The Journal of Bone and Joint Surgery

The Official Publication of
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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The Journal of Bone and Joint Surgery*

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TABLE OF CONTENTS

June 1959

PAGE

Primary Tendon Repair: Editorial.
By *Michael L. Mason, M.D.*, Chicago, Illinois 575

Why Tendon Repair? Editorial.
By *Joseph H. Boyes, M.D.*, Los Angeles, California 577

The Management of Tendon Injuries: Editorial.
By *S. Benjamin Fowler, M.D.*, Nashville, Tennessee 579

Primary Tendon Repairs. A Study of 789 Consecutive Tendon Severances.
By *Alex P. Kelly, Jr., M.D.*, Detroit, Michigan 581

Anatomical Considerations in the Primary Treatment of Tendon Injuries of the Hand.
By *Carl L. Holm, M.D.*, and *Richard P. Embick, M.D.*, Salem, Oregon 599

Excision of the Greater Multangular Bone as an Adjunct to Mobilization of the Thumb.
By *J. Leonard Goldner, M.D.*, and *Frank W. Clippinger, M.D.*, Durham, North Carolina 609

The Carpal-Tunnel Syndrome.
By *Radford Tanzer, M.D.*, Hanover, New Hampshire 626

Dupuytren's Contracture. A New Concept of the Pathogenesis Correlated with Surgical Management.
By *J. Vernon Luck, M.D.*, Los Angeles, California 635

Reconstructive Arterial Surgery in Upper-Extremity Injuries.
By *Robert S. Shaw, M.D.*, Boston, Massachusetts 665

Circulation of the Hand, Injection-Corrosion Studies.
By *J. E. Markee, Ph.D.*, Durham, and *J. B. Wray, M.D.*, Winston-Salem, North Carolina 673

Reconstruction of Congenital Abnormalities of the Upper Extremities.
By *Martin A. Entin, M.D.*, Montreal, Quebec, Canada 681

(Continued on page 3)

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TABLE OF CONTENTS

(Continued from page 1)

PAGE

Thrombofibrosis of the Ulnar Artery in the Palm.
By *Daniel G. Costigan, M.D., James M. Riley, Jr., M.D.,* and *Fred E. Coy, Jr., M.D.,* Louisville, Kentucky 702

Arthroplasty of the Hip in Rheumatoid Arthritis. A Follow-up Study of Sixty-eight Hips.
By *J. R. Schwartzmann, M.D.,* Tucson, Arizona 705

Rheumatoid Synovial Cyst of the Hip. Report of Three Cases.
By *Mark B. Coventry, M.D., Howard F. Polley, M.D.,* and *Alan D. Weiner, M.D.,* Rochester, Minnesota 721

The Measurement of Hip Motion in the Sagittal and Coronal Planes.
By *Henry Milch, M.D.,* New York, N. Y. 731

Spectrochemical Determination of Trace Metals in Normal Striated Muscle in the Rabbit.
By *Patrick G. Laing, M.B., F.R.C.S., Albert B. Ferguson, Jr., M.D.,* and *E. S. Hodge, Ph.D.,* Pittsburgh, Pennsylvania 737

Active Shoulder Motion in Complete Deltoid Paralysis.
By *Colonel Ernst Dehne* and *Major Robert M. Hall,* Medical Corps, United States Army 745

Fracture-Dislocation of the Ankle. An Unusual Cause of Failure of Reduction. Case Report.
By *Thomas F. Parrish, M.D.,* Nashville, Tennessee 749

A New Hip-Nailing Ruler.
By *Albert L. Berndt, M.D.,* Portsmouth, Ohio 751

Proceedings:
The American Academy of Orthopaedic Surgeons 753

The Orthopaedic Research Society 769

American Society for Surgery of the Hand 774

1958 Revision of Diagnostic Criteria for Rheumatoid Arthritis.
Reprinted from the *Bulletin on Rheumatic Diseases* 781

Book Reviews 783

List of Advertisers ..... Adv. 60

Addresses of Contributors ..... Adv. 64

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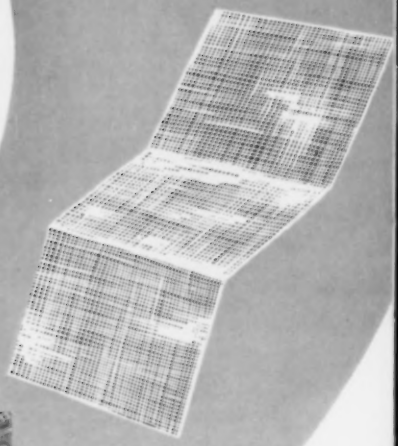

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1. Savastano, A. A. et al.: Rhode Island M. J. *41*:425, 1958. 2. Thomson, J. E. M.: Orthopedics *1*:122, 1959. 3. Beegel, P. M.: J. Maine M. A. *49*:86, 1958. 4. Moore, A. T.: J. Bone & Joint Surg. *39A*:811, 1957. 5. Breck, L. W.: Southwestern Med. *35*:207, 1954. 6. Breck, L. W. et al.: Clin. Orthop. No. 12, p. 183, 1958.

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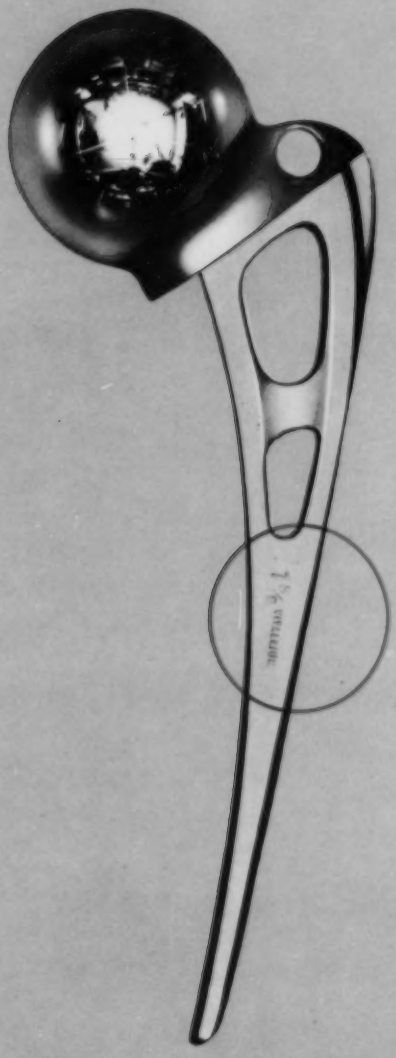

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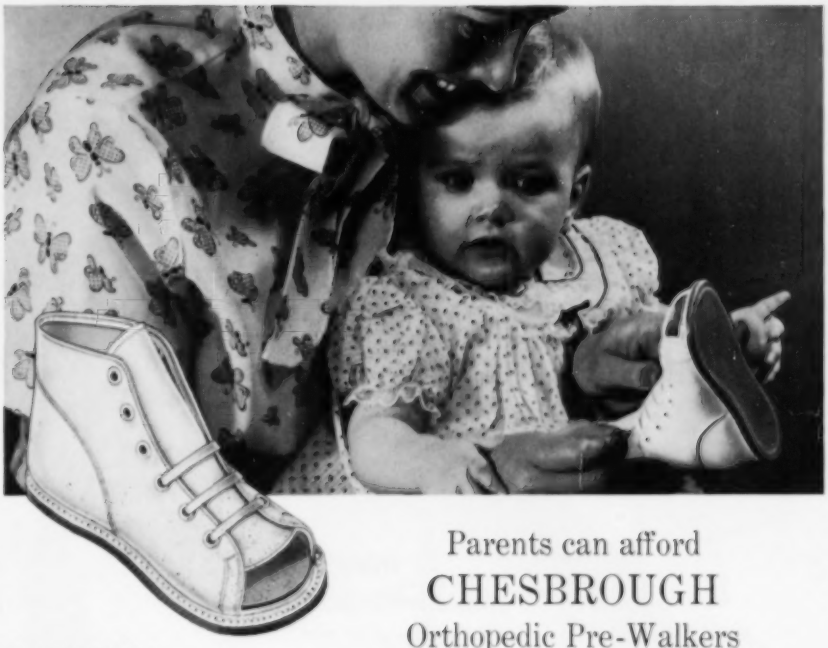

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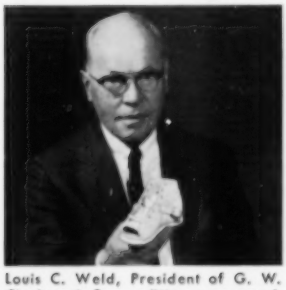

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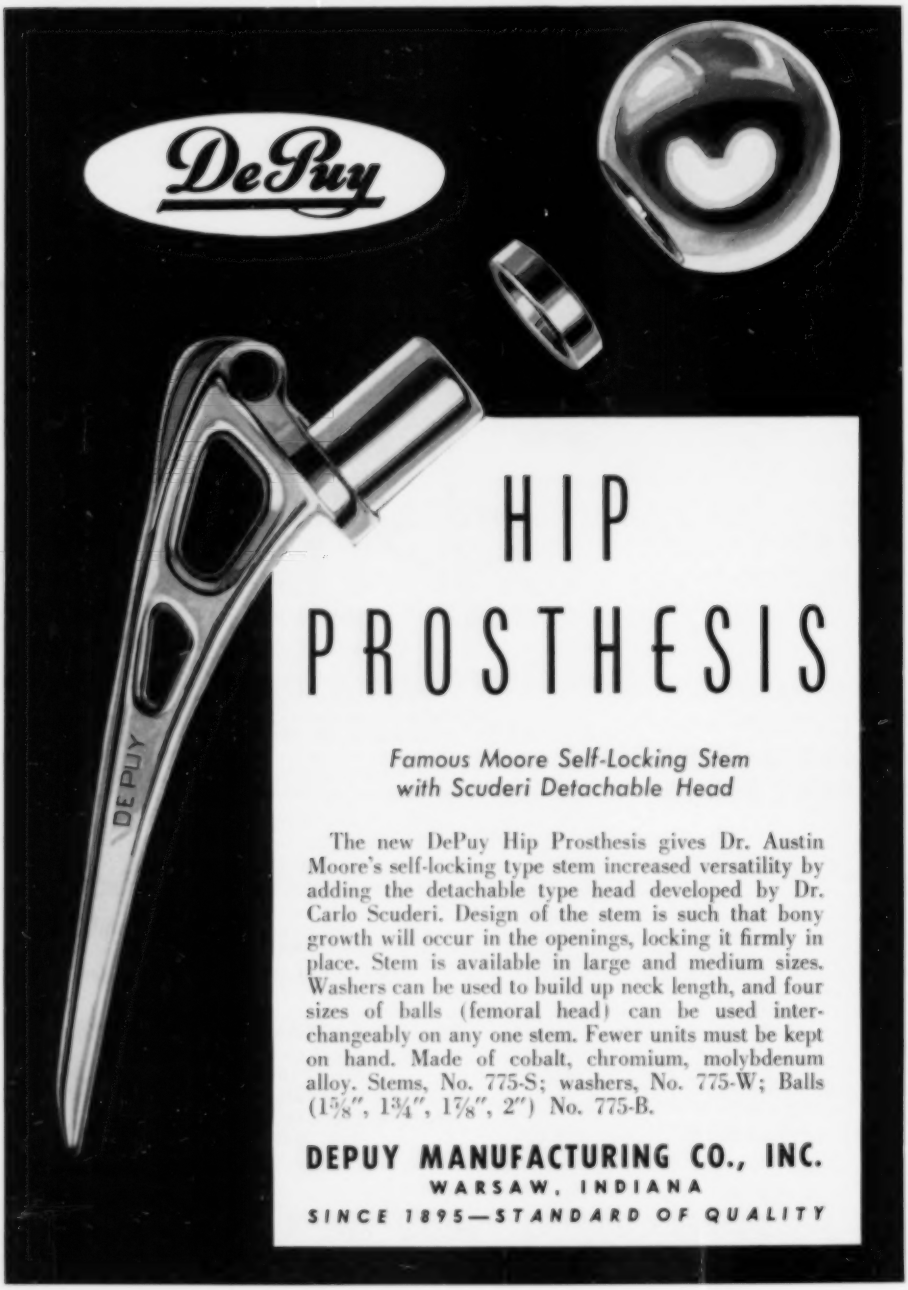

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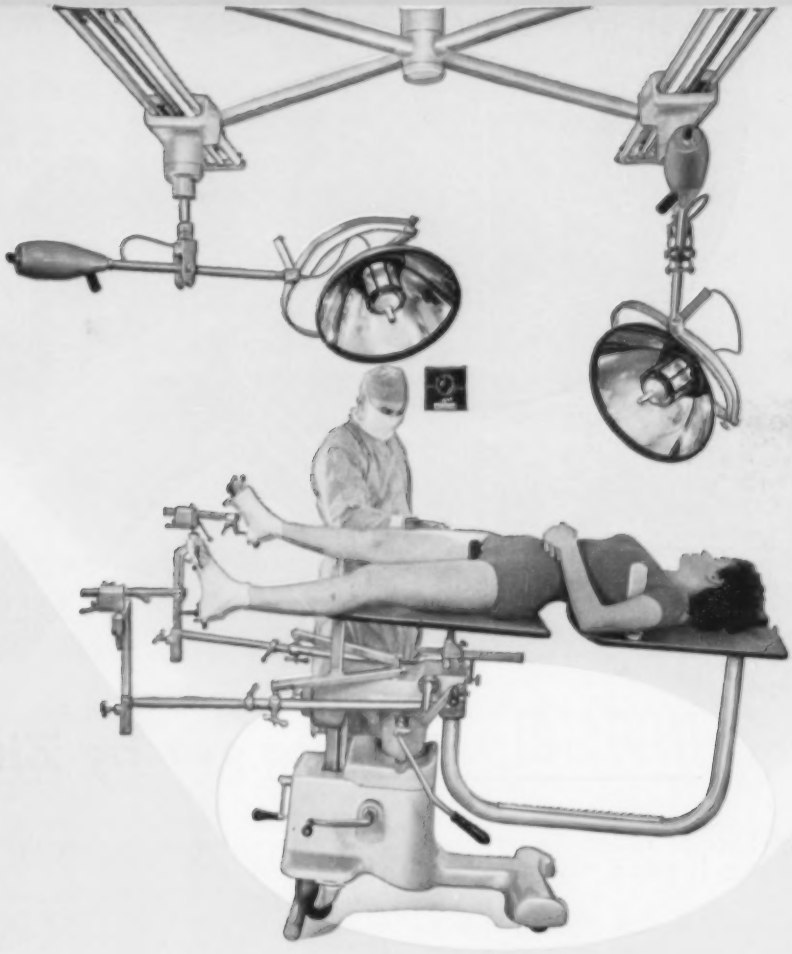

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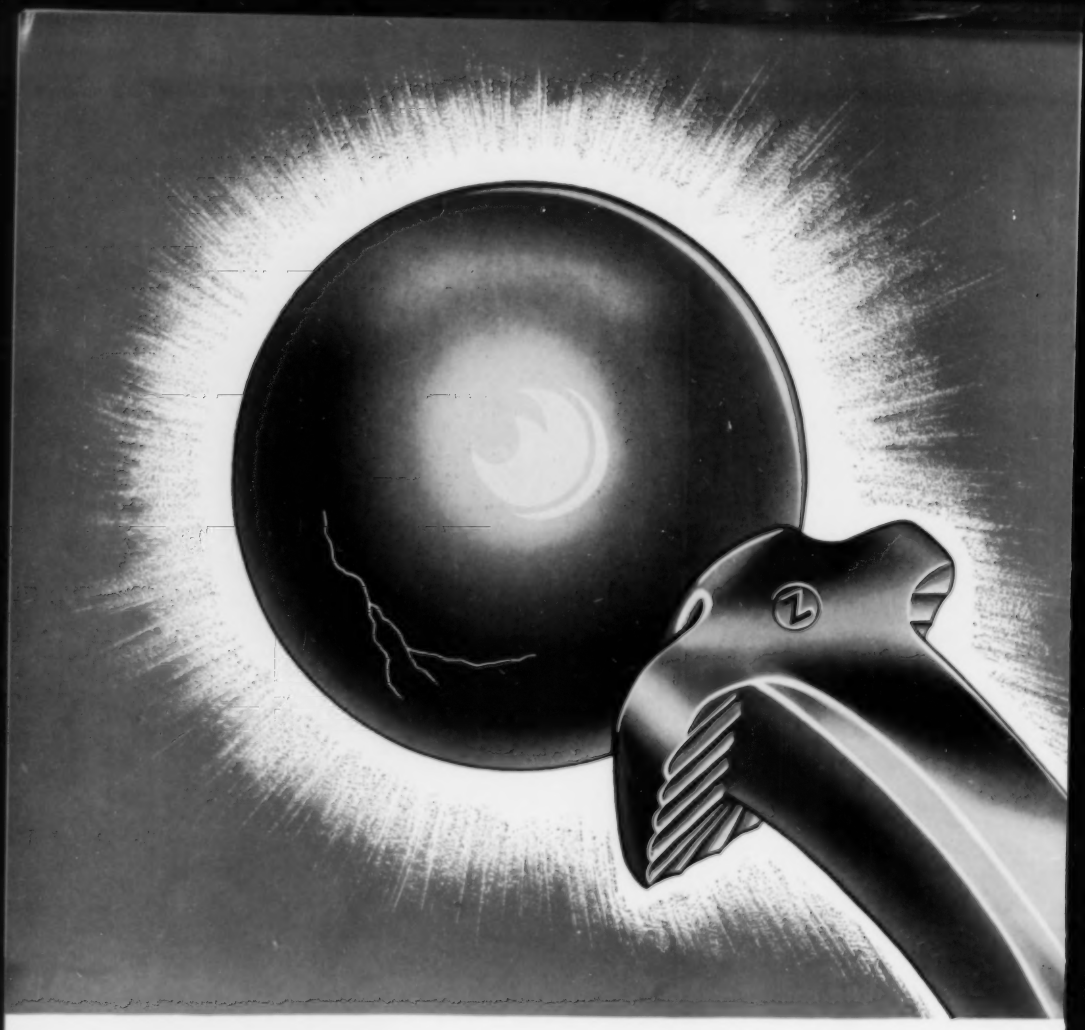

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Such precise quality control is one rea that the Zimmer name has become a warra of excellence . . . and the reason you can sure Zimmer appliances add "extra" s guards to your surgery.

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LOOK FOR THE TRADEMARK Ⓩ

appliances for orthopedic surgery

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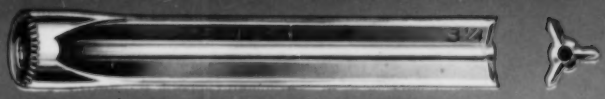
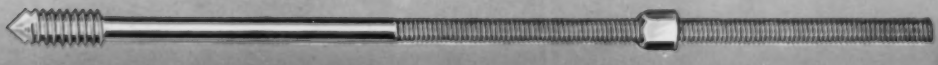


SMITH-PETERSEN NAIL NO. 96

LORENZO SCREW NO. 970

HIP SCREW NO. 259

ZIMMER TIBIA BOLT NO. 463



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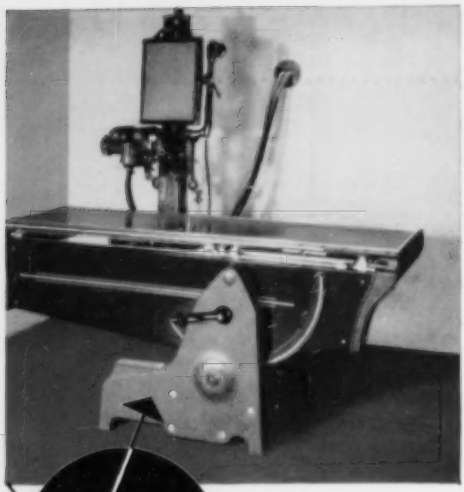

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- Enjoy the most modern x-ray facilities . . . avoid obsolescence losses
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Here's the perfect answer for a cost-saving x-ray installation, easy to keep abreast of important new developments. G-E Maxiservice ties up *none* of your capital . . . eliminates trade-in losses — progress determines your time for exchange, not finances. In effect, you contract for *utility, convenience, flexibility* and *service,* not for just equipment.

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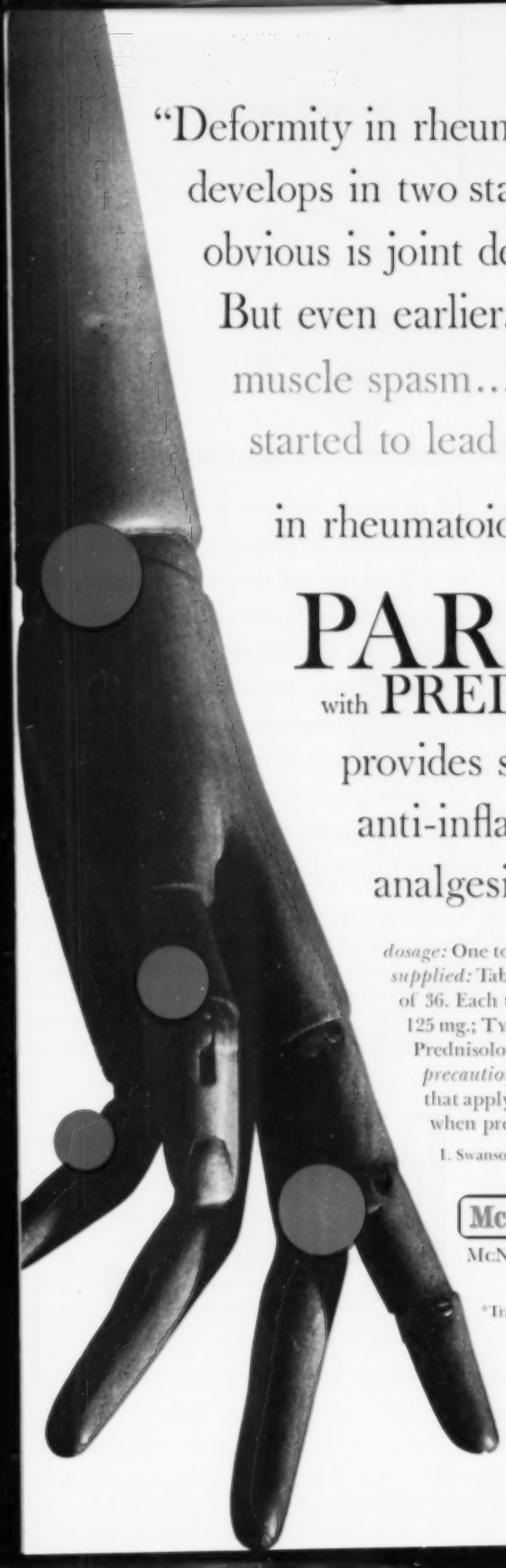


"Deformity in rheumatoid arthritis develops in two stages. The most obvious is joint destruction. But even earlier...

muscle spasm...has insidiously started to lead to deformity."[1]

in rheumatoid arthritis...

PARAFON*

with PREDNISOLONE

provides spasmolytic, anti-inflammatory, and analgesic action

dosage: One to two tablets three or four times a day.

supplied: Tablets, scored, buff colored, bottles of 36. Each tablet contains PARAFLEX® Chlorzoxazone† 125 mg.; TYLENOL® Acetaminophen 300 mg.; and Prednisolone 1.0 mg.

precautions: The precautions and contraindications that apply to all steroids should be kept in mind when prescribing PARAFON WITH PREDNISOLONE.

1. Swanson, J. N.: Canad. M. A. J. 79:638 (Oct. 15) 1958.

McNEIL

McNEIL LABORATORIES, INC • PHILADELPHIA 32, PA.

*Trade-mark †U.S. Patent Pending

265459

mind and muscle

in skeletal-muscle disabilities . . .

for whole-patient response in spasm,

Of all muscle relaxants in current use, only meprobamate is supported by hundreds of clinical studies that demonstrate relaxing action on both brain and skeletal musculature. This is why EQUANIL stands as the obvious choice of many physicians concerned with whole-patient response. EQUANIL reduces muscular spasm and tension, aids in the restoration of mobility, speeds rehabilitation, lessens the emotional overlay.[1-6] Its margin of safety is shared by few agents in medical practice.

1. Mitchell, E.H.: M. Ann. District of Columbia *27*:190 (April) 1958. 2. Cooper, C.D., and Epstein, J.H.: Am. J. M. Sc. *235*:448 (April) 1958. 3. Vazuka, F.A.: Neurology *8*:446 (June) 1958. 4. Cobey, M.C.: Am. Surgeon *24*:350 (April) 1958. 5, 6. Wein, A.B.: M. Ann. District of Columbia *27*:346 (July) 1958; Clin. Med. *6*:44 (Jan.) 1959.

Equanil®

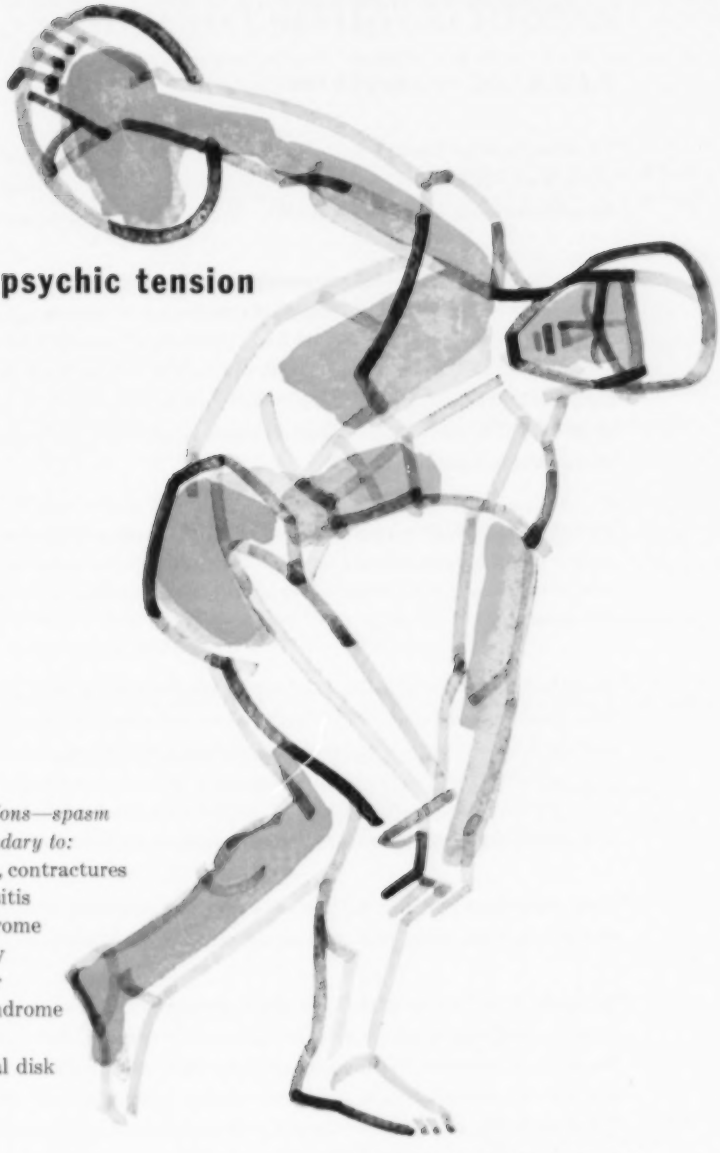
Meprobamate, Wyeth

Wyeth

Philadelphia 1, Pa.

. . . specific central action

rigidity, psychic tension



Partial indications—spasm or tension secondary to:
sprains, strains, contractures
fibrositis, myositis
low-back syndrome
whiplash injury
frozen shoulder
cervical-rib syndrome
herniated intervertebral disk
wryneck
rheumatoid arthritis
rheumatoid or traumatic spondylitis
certain neuromuscular disorders

. . . specific muscular action

HIGHLIGHTS FROM THE A.M.A. COUNCIL ON DRUGS

REPORT ON TRIAMCINOLONE

J.A.M.A. 169:257 (January 17) 1959.

"It [triamcinolone] has an anti-inflammatory potency greater than an equal amount of prednisolone; i.e., comparable suppressive effects may usually be achieved with lower doses of triamcinolone than with prednisolone."

"Triamcinolone lacks the sodium-retaining and edema-producing effects of most other glucocorticoids. During the first several days of administration, it may cause a loss of sodium from the body; an initial mild diuretic action is frequently observed, whether the patient is frankly edematous or not. This is in contrast to the definite sodium-retaining and fluid-retaining properties of cortisone and hydrocortisone and to a much lesser extent with prednisone and prednisolone."

"Except in exceedingly large doses, triamcinolone apparently has no consistent effect on potassium excretion. Hence, neither sodium restriction nor potassium supplementation is ordinarily required during therapy with this agent."

"As with other glucocorticoids, the long-term administration of triamcinolone results in definite catabolic effects, as indicated by impairment of carbohydrate utilization and negative protein and calcium balance. This catabolic effect, coupled with a lack of appetite stimulation which is apparently peculiar to triamcinolone, may produce weight loss that might be undesirable in some patients treated for long periods of time."

"...the voracious appetite, with weight gain and euphoria, characteristic of other steroids, is not seen with administration of triamcinolone."

"Triamcinolone has been used for the management of a wide variety of clinical conditions usually considered amenable to systemic steroid therapy. These have included rheumatoid arthritis and other collagen diseases, allergic and dermatological disorders, certain leukemias and malignant lymphomas, the nephrotic syndrome, pulmonary emphysema and fibrosis, acute bursitis, rheumatic fever, and certain blood dyscrasias. Although clinical experience with the drug in some of the foregoing conditions is not extensive, the many similarities in action between triamcinolone and other potent glucocorticoids would indicate a usefulness for triamcinolone akin to that of other agents of this class."

"There is some evidence that triamcinolone is more effective at a smaller dosage than are other steroids in controlling both the skin and joint lesions in psoriasis, whether or not complicated by arthropathy."

"Triamcinolone appears to compare favorably with other steroids for use in those situations in which edema and sodium retention have been complicating problems."

"It [triamcinolone] may also be the steroid of choice for patients in whom psychic stimulation, euphoria, voracious appetite, and weight gain should be avoided."

"...the drug [triamcinolone] does produce the other side effects and untoward reactions common to the glucocorticoids. At therapeutically equivalent doses, the frequency and severity of clinical manifestations of hyperadrenalism — rounding of the face, fat deposition, and hirsutism — are essentially the same. Likewise, there is little indication that the relative incidence of osteoporosis is materially decreased after the long-term use of the drug."

"Triamcinolone apparently does not cause the euphoria sometimes seen with other steroids, and the occurrence of mental depressions is uncommon."

"Current evidence suggests that the drug [triamcinolone] may not produce as high an incidence of peptic ulcer as do other steroids."

"Cutaneous erythema seems to be a side effect peculiar to triamcinolone."

"The usual contraindications and precautions of glucocorticoid therapy should be followed in the use of triamcinolone, keeping in mind that prolonged therapy with this drug will suppress the function of the patient's own adrenals by interfering with the pituitary-adrenal axis."

Aristocort®

Triamcinolone LEDERLE

Supplied: 1 mg. scored tablets (yellow)
2 mg. scored tablets (pink)
4 mg. scored tablets (white)

Lederle

LEDERLE LABORATORIES, A Division of AMERICAN CYANAMID COMPANY, Pearl River, New York

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A pilot for the past four years

Charles Myers, an above-knee amputee, wore his first Hanger Limb over eight years ago. "During that time I was in Central America, Mexico, and Canada. In Central America I worked on air route surveys under jungle conditions. I found that my Hanger Limb stood up well." The sturdiness and dependability of the Hanger Limb allows wearers to return to normal life. Many, such as Mr. Myers, are happy to find they can continue strenuous and unusual occupations.

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AVAILABLE AT AUTHORIZED FACILITIES IN THE FOLLOWING CITIES:

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CHARLESTON 2, W. VA.
NEW YORK 11, N. Y.
PHILADELPHIA 7, PA.
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RICHMOND 19, VA.
ROANOKE 12, VA.
WASHINGTON 13, D. C.

Midwestern Region:
CHICAGO 5, ILL.
CINCINNATI 29, OHIO
DALLAS 1, TEXAS
EVANSVILLE, IND.
FORT WAYNE, IND.
INDIANAPOLIS 2, IND.
OKLAHOMA CITY 3, OKLA.
PEORIA 4, ILL.
ST. LOUIS 66, MO.
WICHITA, KANS.

Southeastern Region:
ATLANTA 9, GA.
BIRMINGHAM 1, ALA.
COLUMBIA 5, S. C.
JACKSONVILLE, FLA.
MIAMI 37, FLA.
MOBILE, ALA.
MONTGOMERY, ALA.
NASHVILLE 5, TENN.
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STOP... Read... and Heed

Here's a brand-new, easy-to-follow chart that will help you obtain radiographs of better diagnostic quality.

Now, with accurate, *time-temperature x-ray film processing*, you can standardize exposures—keep each exposure to the minimum; reduce retakes.

Use the coupon now to send for free copy of "The ABC's of X-ray Film Processing"—published by Kodak as a service to the medical profession.

Note: Kodak Royal Blue Medical X-ray Film—the fastest medical x-ray film available—provides maximum information with minimum exposure when processed according to this chart.

Order from your Kodak x-ray dealer.

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SPECIAL . . .
Fill Out . . .
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Medical Division, Rochester 4, N. Y.
Please send—free—"The ABC's of X-ray Film Processing."

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RUBBER ELASTIC BANDAGE

ASSURES MORE UNIFORM SUPPORT

Scientifically determined number of rubber and cotton threads provides a **balanced weave** that assures optimal therapeutic results.

ACE guarantees even and controlled stretch

ACE insures firmness under tension

ACE prevents "bunching"

ACE minimizes possibility of vein constriction

MAINTAINS ITS ELASTICITY LONGER

Today, ACE provides your patient with anatomically correct support far longer. B-D's newly developed type of heat-resistant rubber can withstand dry heat sterilization and has a greater tensile strength than rubber found in ordinary bandages.

Now, more than ever, ACE is the name to remember. Only Becton, Dickinson and Company makes ACE rubber elastic bandage.

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B-D AND ACE ARE REGISTERED TRADEMARKS OF BECTON DICKINSON AND COMPANY

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FOR
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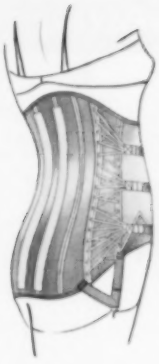
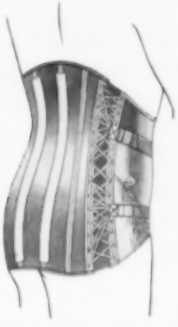
Freeman SURGICAL SUPPORTS



MODEL 423
Sacro-Lumbar Back
Support for Women



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Support For Men

For 68 years Freeman has worked closely with orthopedic surgeons to design surgical garments that provide *correct* support. Each garment is made by skilled craftsmen using the finest materials available.

There's a quality Freeman support for most every application. You can be certain that the garment you select will carry out your prescription to the best possible satisfaction of you and your patient.

Freeman corset-type back supports provide bracing in any desired degree to almost complete immobilization. Special construction features assure comfort for the wearer in sitting, standing and reclining positions.

FREEMAN QUALITY FEATURES

New Dacron-Pima Cotton Fabric. Petal-Soft Interior Finish cushions the stays, avoids irritation. Self-Smoothing, Exclusive Non-Wrinkle Fly speeds putting on garment and avoids comfort-robbing wrinkles. Soft Plush Padding under hooks and eyes. Superb Needle Work.

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with Confidence!

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Please send details on new Freeman features and include free reference catalog.

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FOR SELF-ADMINISTERED INHALATION ANALGESIA

IN OBSTETRICS **IN MINOR SURGERY** **IN PEDIATRICS**

"Trilene"® *and the*

Brand of trichloroethylene U.S.P. (Blue)

"Duke"® University Inhaler

No. 3160 Model-M

- *notably safe and effective*

"Trilene," self administered with the "Duke" University Inhaler, under proper medical supervision, provides highly effective analgesia with a relatively wide margin of safety.

- *convenient to use*

The "Duke" University Inhaler (Model-M) is specially designed for economy, facility of handling, and ready control of vapor concentration.

- *special advantages*

Induction of analgesia is usually smooth and rapid with minimum or no loss of consciousness. Patients treated on an ambulatory basis can usually leave the doctor's office or hospital within 15 to 20 minutes. Inhalation is automatically interrupted if unconsciousness occurs.

"Trilene" *alone* is not recommended for anesthesia nor for the induction of anesthesia. Epinephrine is contraindicated when "Trilene" is administered.

"Trilene" is available in 300 cc. containers.

Ayerst Laboratories • New York, N. Y. • Montreal, Canada

Ayerst Laboratories make "Trilene" available in the United States by arrangement with Imperial Chemical Industries Limited.

5718

Spencer Does the Whole Job

This patient's Spencer was designed to meet all of her support requirements:

- To improve body alignment. (A shortened leg, the result of an automobile accident, had seriously affected body alignment, making walking difficult and causing hip pain.)
- To elevate her heavy abdomen.
- To provide comfortable, healthful support for her entire body.

Spencer was able to do all this in one support because every *Spencer Support* . . .

- Is designed *individually* to the exact measurements of the patient who is to wear it.
- Scientifically correlates back and abdominal support.
- Is made to incorporate any combination of features required to meet the patient's *total* support needs.

Spencer first realigns the body... then designs a support to hold it that way.

Spencer's Individual Designing Service is available to you through Corsetieres specially trained to help you help your patients.

SPENCER®

individually designed supports for women, men and children

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☐ Send me the name of the nearest Spencer Corsetiere.

☐ I would like an office demonstration of Spencer benefits and features.

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Address _____

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6-59

KENACORT

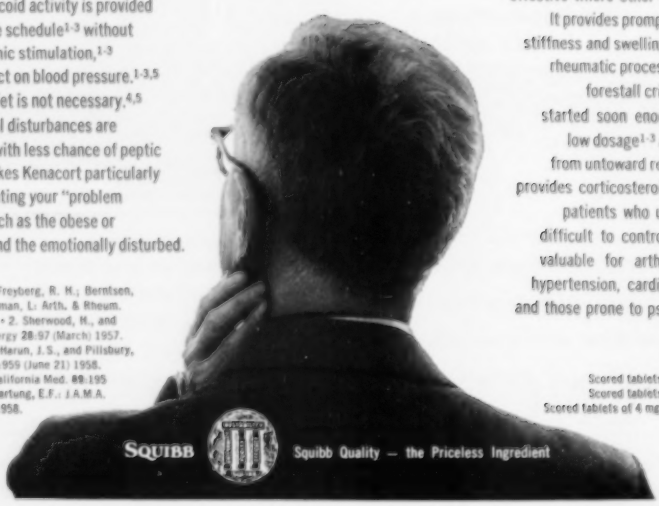
SQUIBB TRIAMCINOLONE

for all your patients starting on corticoids

Kenacort safely starts your patients off right — with all the benefits of systemic corticosteroid therapy and few side effects to worry about. Increased corticoid activity is provided on a low dosage schedule[1-3] without edema,[1-4] psychic stimulation,[1-3] or adverse effect on blood pressure.[1-3,5] A low sodium diet is not necessary.[4,5] Gastrointestinal disturbances are negligible[2,4,5] with less chance of peptic ulcer.[4] This makes Kenacort particularly valuable in treating your "problem patients" — such as the obese or hypertensive and the emotionally disturbed.

for all your arthritic patients requiring corticoids

Kenacort, particularly in the treatment of your arthritic patients, has proved effective where other steroids have failed. It provides prompt, safe relief of pain, stiffness and swelling by suppressing the rheumatic process[1,5] — and may even forestall crippling deformities if started soon enough. Because of its low dosage[1-3] and relative freedom from untoward reactions,[1-5] Kenacort provides corticosteroid benefits to many patients who until now have been difficult to control. It is particularly valuable for arthritic patients with hypertension, cardiac disease, obesity and those prone to psychic disturbances.



SUPPLIED:
Scored tablets of 1 mg. — Bottles of 50
Scored tablets of 2 mg. — Bottles of 50
Scored tablets of 4 mg. — Bottles of 30 and 100

REFERENCES: • 1. Freyberg, R. H.; Berntsen, C. A., Jr., and Hellman, L.: Arth. & Rheum. 1:215 (June) 1958. • 2. Sherwood, H., and Cooke, R. A.: J. Allergy 28:97 (March) 1957. • 3. Shelley, W. B.; Harun, J. S., and Pillsbury, D. M.: J.A.M.A. 167:959 (June 21) 1958. • 4. Dubois, E.L.: California Med. 89:195 (Sept.) 1958. • 5. Hartung, E.F.: J.A.M.A. 167:973 (June 21) 1958.

SQUIBB

Squibb Quality — the Priceless Ingredient

For the first time...

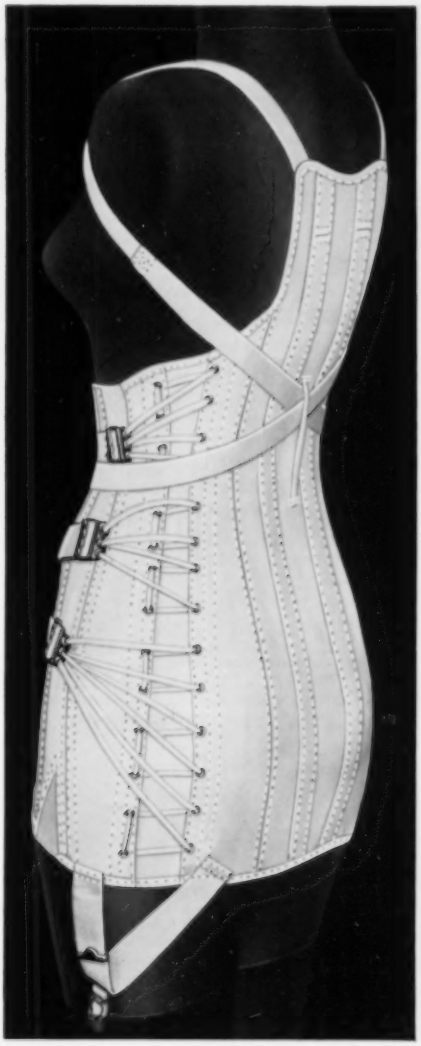
a dorso-lumbar support with single adjustment of shoulder straps in front to assure correct support

It's always been a problem for the patient to adjust satisfactorily the conventional dorso-lumbar support. In order to adjust shoulder straps at each side, the patient has to turn the shoulders out of normal position. This makes it difficult to attain the optimum support for the upper back.

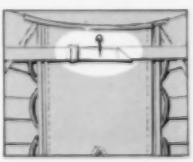
Now Truform has the answer . . . shoulder straps that are tightened by a single adjustment in front, as shown in the drawing. No twisting and turning to each side. The patient's shoulders stay in their normal position, the adjustment firmly maintains the desired corrective position. The tightened straps, which cross in the back, are then held securely in a simply designed "keeper" (shown in drawing).

Greater height in the back, too, with two full-height steel stays to assure firm support. Comfortable adjustable underarm pads . . . 3 pull-straps to adjust and distribute tension.

Always look to Truform supports that are anatomically correct and therapeutically sound . . . fitted with skillful knowledge . . . available to you and your patients only from the Ethical Appliance Dealer.



NEW DORSO-LUMBAR SUPPORT



Women's models 1173-HS full skirt (pictured above) and 1174-HS regular length. Men's model 417-HS regular length. Drawing shows single adjustment of shoulder straps in front, retained in "keeper".

TRUFORM *anatomical supports*

3960 Rosslyn Drive, Cincinnati 9, Ohio

Branches: New York and San Francisco

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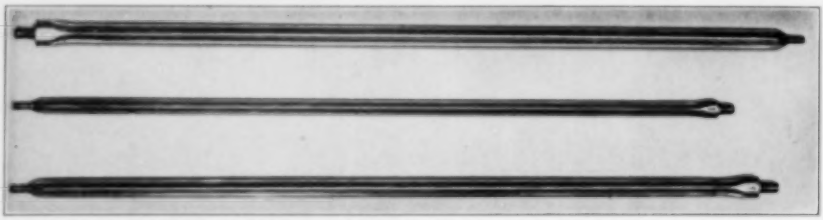
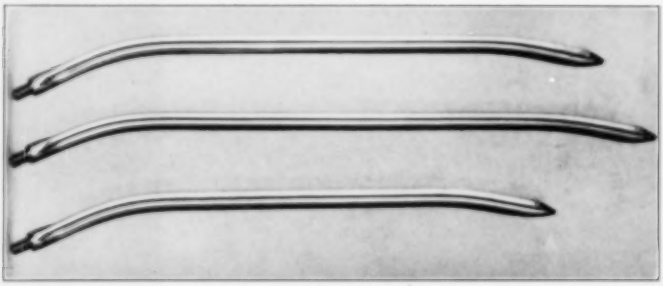
LOTTES NAILS and INSTRUMENTS

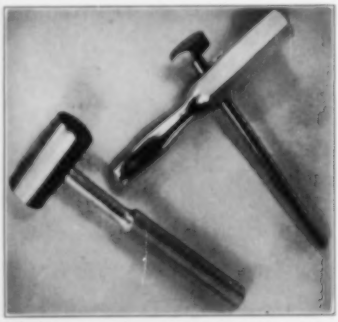


LOTTES **FEMORAL NAILS** are manufactured with diameters of 3/8, 7/16, and 1/2 inches —with lengths in 1/2 inch variations from 14 to 20 inches.

LOTTES **TIBIAL NAILS** are made in 5/16 and 3/8 inch diameters—in lengths from 9 to 15 1/2 inches, in variation of 1/2 inch.



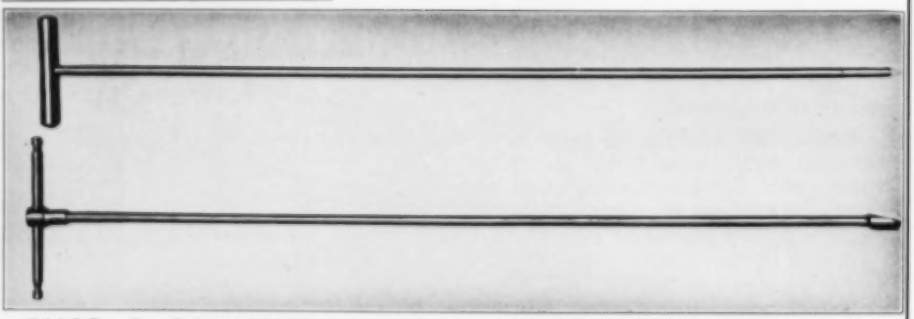
LOTTES NAILS AND INSTRUMENTS ARE MADE OF 18-8 SMo STAINLESS STEEL



LOTTES **DRIVER-EXTRACTOR COMBINATION and** ***LOTTES*** **MALLET**

LOTTES **GUIDE WIRE AND** ***LOTTES*** **REAMER**

The reamer comes in 3 diameters: 3/8, 7/16, and 1/2 inch—all are 23 inches in length.

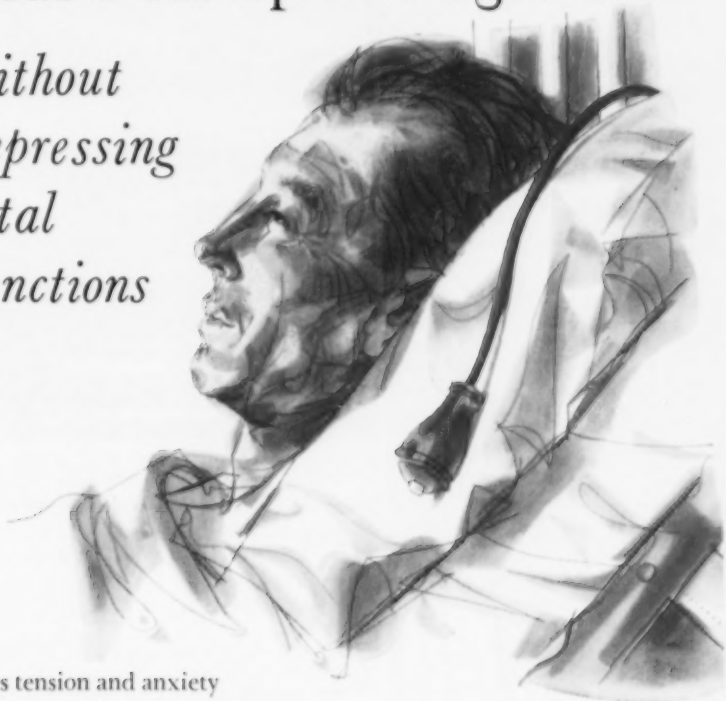


CHAS. A. SCHMIDT SURGICAL INSTRUMENT COMPANY

3689 Olive Street, Saint Louis 8, Missouri

Relieves Pre-op Apprehension Aids Post-op Management

without depressing vital functions



- relieves tension and anxiety
- helps provide "a good night's sleep"
- facilitates early ambulation
- relaxes skeletal muscle

Miltown has no adverse effects on cardiovascular, respiratory or gastrointestinal functions and causes no depressive "hang-over"

Miltown®

meprobamate (Wallace)

Miltown is available in 400 mg. scored and 200 mg. sugar-coated tablets; bottles of 50.

®WALLACE LABORATORIES
New Brunswick, N. J.

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1. Kern, E. C.: Preoperative sedation with meprobamate (Miltown) in surgery of eye, ear, nose and throat. Eye, Ear, Nose & Throat Month. 36:408, July 1957.
2. Lamphier, T. A.: The value of meprobamate preoperatively. Maryland M.J. 7:627, Nov. 1958.
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5. Rushia, E. L.: Preliminary report on the use of meprobamate for pre-anesthetic sedation. J.M.A. Georgia 46:93, March 1957.
6. Sadove, M. S. and Schiffrin, M. J.: Tranquilizers in surgery, in Surg. Clin. North America, Saunders, Philadelphia, Feb. 1959, pp. 231-244.

CM-8879

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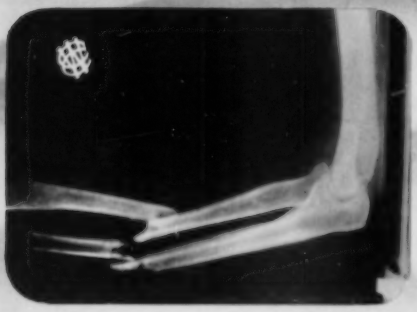
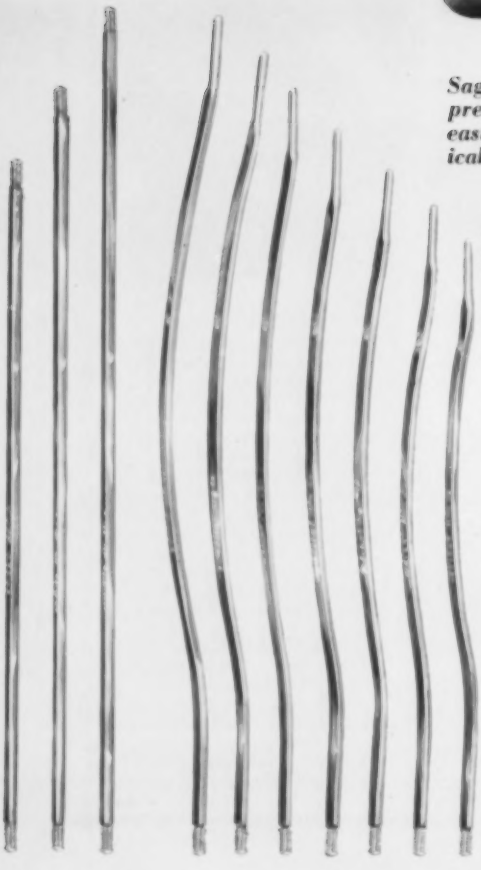


sage pins

Sage Triangular Forearm Pins have precision formed contours to allow easier insertion and aid in anatomical alignment.

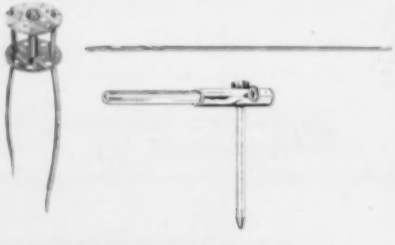


MADE OF NON-MAGNETIC, INERT, SMO STAINLESS STEEL . . . SPRING TEMPERED TO A SPECIAL ROCKWELL-HARDNESS.

Pre-formed (one end threaded) Radius Pins available in seven lengths, graduated in ½-inch increments from 8 to 11 inches. Straight (both ends threaded) Ulna Pins available in three lengths, graduated in 1-inch increments from 9 to 11 inches. Radius and Ulna Pin diameters are either 4.4 mm or 5 mm.

COMPLETE SET CONSISTS OF SEVEN RADIUS PINS, THREE ULNA PINS AND PIN HOLDING RACK.

THE REAMER DRILL AND DRIVER EXTRACTOR ARE ESPECIALLY DESIGNED FOR USE WITH THESE PINS. THE DRILLS ARE CORRECTLY SIZED TO ASSURE EASY INSTALLATION AND MAXIMUM HOLDING POWER.



WRIGHT

FOR FURTHER INFORMATION WRITE TO DEPT. W-7

MANUFACTURING COMPANY

880-882 ADAMS, MEMPHIS, TENNESSEE

Child Life SHOES provide

Winged Mismate Service

When mismated shoes are needed, they are needed NOW — not two or three weeks hence. The sooner the shoes arrive, the better for your patient. Because this is so true — and human comfort is important — CHILD LIFE gives special priority to Mismate Service. In nine cases out of ten, shoes are shipped the same day the order is received . . . and they are sent *special delivery* parcel post.

As a physician, it's good to know that this brand of service backs up your recommendations to mothers. And it's good to know, too, that CHILD LIFE Mismate Service carries only a very nominal premium in price. The CHILD LIFE dealer in your community — selected for his special knowledge of children's shoes — will be glad to fill you in on all details. Please write for his name.

Or if you prefer to write direct for information, your inquiry will be welcome and promptly acknowledged.

HERBST SHOE MANUFACTURING COMPANY
MILWAUKEE 45, WISCONSIN

LaBerne Shoulder Rotator

The LaBerne Shoulder Rotator offers Progressive and Resistive Exercises in a complete range, for Internal and External Rotation, Unilateral and Bilateral Extensor, Scapula Rotation, and Elbow Flexor Exercise. Built with Sensitive Resistance-Pressure Plate adjustable in height. Calibrated for 0 to 80 lbs.

Price including table 28 x 30 x 32

Model # 9952 $159.50

Price without table with bracket for attaching to plinth,

Model # 9952-A $ 89.50

Showing Resistance Control Calibration in pounds. →

LaBerne Extension-Flexion Exercise Unit

Designed for a complete range of Progressive Resistive Exercise to the Knee Joint Muscle Group WITHOUT THE USE OF WEIGHTS.

Exercise arm built with Reversible Ratchet on Sensitive Pressure Plate offering any desired resistance calibrated in lbs. from 0 to 80. Range of motion indicator in full view of patient and therapist for accurately following Range Progress. Ideal for use with BK Amputees and BK Fractures, may also be used for Hamstring Exercise, Hip Abduction and Extension. Complete unit including table 28 x 30 x 32 with Quadriceps Rest, Model # 9950

$159.50

Above unit with Shoulder Rotator included, Model # 9951 $239.00

Showing use for BK amputees and fractures. Range of motion dial calibrated in pounds. →

LaBerne Hip Rotator

Designed for complete rotation of Hip Joint. Rotation Plate built at 8° angle to eliminate bending of knee during rotation. Mounted on roller bearings with Adjustable Arc from 4" to 12" circle. Model # 66 $49.50

ALL PRICES FOB COLUMBIA

La Berne MANUFACTURING COMPANY

Columbia, S.C. P.O. Box 5245 Phone SUnset 7-6162

ORIGINATORS OF THE "WALK-OFF" PHYSICAL THERAPY TABLE

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.

PAIN Zactirin®

Ethoheptazine Citrate with Acetylsalicylic Acid, Wyeth

for everyday pain control . . .

for your many patients requiring potent analgesia but not an injected narcotic

Proved by extensive evaluation[1,2,3] in 1998 patients in diverse areas of medicine and surgery, including:

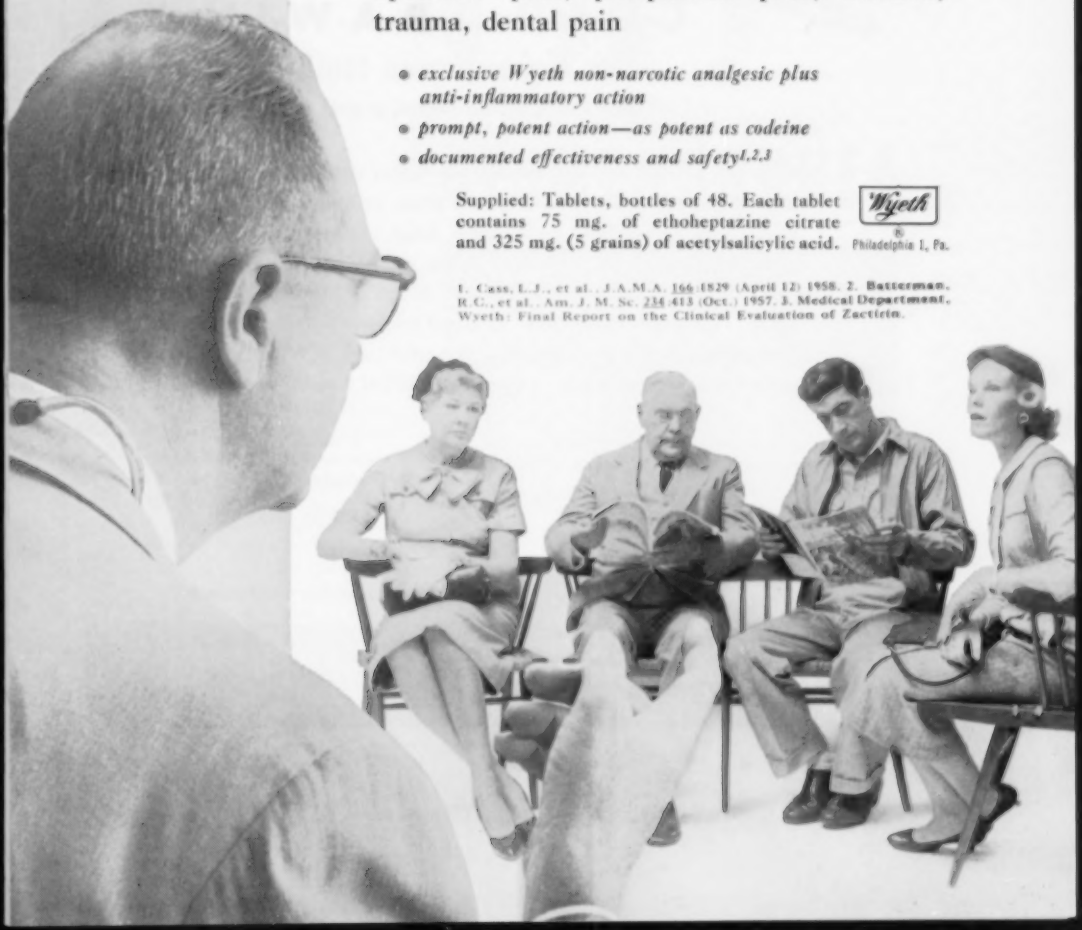
arthritis, bursitis, early metastatic carcinoma, fibrositis, grippe, herpes zoster, ligamental strain, low back pain, menstrual pain, myalgia, myositis, neuritis, pleurisy, postoperative pain, postpartum pain, sciatica, trauma, dental pain

- *exclusive Wyeth non-narcotic analgesic plus anti-inflammatory action*
- *prompt, potent action—as potent as codeine*
- *documented effectiveness and safety[1,2,3]*

Supplied: Tablets, bottles of 48. Each tablet contains 75 mg. of ethoheptazine citrate and 325 mg. (5 grains) of acetylsalicylic acid.

Wyeth®
Philadelphia 1, Pa.

1. Cass, L. J., et al.: J.A.M.A. 166:1829 (April 12) 1958. 2. Batterman, R. C., et al.: Am. J. M. Sc. 234:413 (Oct.) 1957. 3. Medical Department, Wyeth: Final Report on the Clinical Evaluation of Zactirin.



Rely on original Küntscher
CLOVERLEAF medullary NAILS
by Orthopedic

Nails are formed by
C-O-L-D D-R-A-W-I-N-G
for higher proven tensile strength
(not stamped on punch press; not rolled)

Nails are formed by cold-drawing for higher proven tensile strength—not fabricated or stamped on punch press, or rolled. Nail has rounded cusp; no sharp bends or angle points which could cause fracture of the metal. Incidents of Küntscher Nail failure due to breakage are unknown to our customers because of qualitative design and reliability in manufacturing. SMo original Küntscher Cloverleaf medullary nails, instruments and fracture equipment by Orthopedic are available at NO additional cost to the consumer through our company's qualified surgical dealers.

Küntscher
CLOVERLEAF NAILS
All diameters and lengths in stock for immediate delivery.

Write for complete 160-page catalog

Plants in Great Britain and Germany

Orthopedic EQUIPMENT CO.
BOURBON, INDIANA
SPLINTS • FRACTURE EQUIPMENT • SMo INTERNAL BONE APPLIANCES • BONE INSTRUMENTS

effective in **93%**

of 1570 patients with

LOW BACK PAIN

(LUMBAGO, SACROILIAC DISORDERS)

effective in **88%**

of 443 patients with

DYSMENORRHEA

AND PREMENSTRUAL TENSION

Dosage: 1 or 2 Caplets® of 100 mg. orally three or four times daily. Relief of symptoms occurs in from fifteen to thirty minutes and lasts from four to six hours.
Supplied: Trancopal Caplets (scored) 100 mg., bottles of 100.

Clinical studies of over 4400 patients by 105 physicians[1] proved Trancopal remarkably effective in musculoskeletal conditions, anxiety and tension states

INDICATIONS

Musculoskeletal

Low back pain (lumbago) / Disc syndrome / Neck pain (torticollis) / Fibrositis / Bursitis / Ankle sprain, tennis elbow / Rheumatoid arthritis / Myositis / Osteoarthritis / Postoperative muscle spasm

Psychogenic

Dysmenorrhea / Angina pectoris / Anxiety and tension states / Asthma / Premenstrual tension / Alcoholism

*the first true tranquilaxant**

Trancopal®

Potent MUSCLE RELAXANT
. . . *Equally effective as a* TRANQUILIZER

*tran-qué-lax-ant (tran'kwi-lak'sent) [< L. *tranquillus*, quiet; L. *laxare*, to loosen, as the muscles]

1. Collective Study, Department of Medical Research, Winthrop Laboratories.

Winthrop LABORATORIES
New York 18, N. Y.

TRANCOPAL (BRAND OF CHLORMEZANONE) AND CAPLETS, TRADEMARKS REG. U. S. PAT. OFF.

IS THIS YOUR PATIENT?

1.

EARLY POSTMENOPAUSE

Complains of low back pain, vague aches and fatigue

Posture is poor

No x-ray evidence of bone lesions

2.

LATER POSTMENOPAUSE

Back pain is severe, spreading to hips ("girdle pain")

Patient is round shouldered, walks with a stoop

X-ray reveals compression fractures of lower vertebrae

3.

70 AND OVER

Fracture of hip after a minor fall

X-ray reveals fracture of neck of femur

X-ray reveals compression fractures of lower lumbar vertebrae

These three patients have osteoporosis. Early diagnosis and treatment with "Formatrix" is important because osteoporosis is probably the only age change that can be averted. With "Formatrix" therapy, relief from the symptoms of *low back pain, vague aches* and *fatigue* may be obtained in as little as a few weeks. "Formatrix" supplies the essential materials to stimulate increased bone formation and prevent further loss of bone substance that leads eventually to loss of height, stooped posture, and disabling fractures.

The highest incidence of osteoporosis may be found among the 14,000,000 women in the U.S.A. who are 55 years of age and over. Some investigators claim that almost all women past the menopause will show some degree of osteoporosis; furthermore, if all these women were examined carefully, 50 per cent would show x-ray evidence of decreased bone mass.

Suspicion may be the handiest diagnostic tool since presenting symptoms vary from mild to severe and incapacitating pain, and no x-ray evidence of spinal degeneration is available until about 30 per cent of the bone matrix is lost. Between these two extremes there are other signs of estrogen deficiency such as *wrinkled and thinning skin*, a *tendency to appear older than stated years;* there may also be *hypercalciuria* when postmenopausal osteoporosis is complicated by acute osteoporosis of disuse.

Osteoporosis is primarily an atrophic condition of bone matrix formation and any factor that depresses osteoblastic activity or retards the formation of protein and connective tissue such as *prolonged immobilization, cortisone therapy,* or *malnutrition* will favor development of osteoporosis in both male and female.

5878

Ayerst

AYERST LABORATORIES
New York 16, N. Y. • Montreal, Canada

NEW

In answering advertisements, please mention *The Journal of Bone and Joint Surgery.*

"FORMATRIX" contains three most essential bone building materials necessary *for matrix* formation, estrogen, androgen and vitamin C.

The estrogen component of "Formatrix" stimulates osteoblastic activity, thus aiding calcium and phosphorus deposition; it also imparts a feeling of "well-being." The anabolic action of methyltestosterone promotes the synthesis of protein and restores a positive nitrogen balance. Together, these hormones have a greater effect on bone and protein metabolism than either alone, and side effects are minimized because of the opposing action of the two steroids on sex-linked tissues. Vitamin C plays an important role in formation of intercellular cement substance and amino acid synthesis. "Formatrix" has a large amount of vitamin C to aid in new bone matrix formation and to further help in the healing of fractures.

"FORMATRIX" – each tablet contains:

Conjugated estrogens equine ("Premarin"®)	1.25 mg.
Methyltestosterone	10.0 mg.
Ascorbic acid	400.0 mg.

Dosage: 1 tablet a day – In the female, three weeks of treatment with a rest period of one week between courses is recommended.

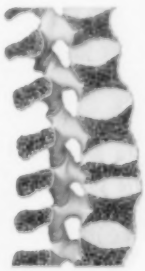
Supplied: Tablets, bottles of 60 and 500.

LITERATURE AVAILABLE ON REQUEST

1.

EARLY POSTMENOPAUSE
No x-ray evidence of bone lesion

2.



LATER POSTMENOPAUSE
X-ray reveals compression fracture of lower vertebrae

3.

70 AND OVER
X-ray reveals fracture of neck of femur

TO RELIEVE LOW BACK PAIN – TO PROMOTE HEALING OF FRACTURES

in osteoporosis

'FORMĀTRIX'

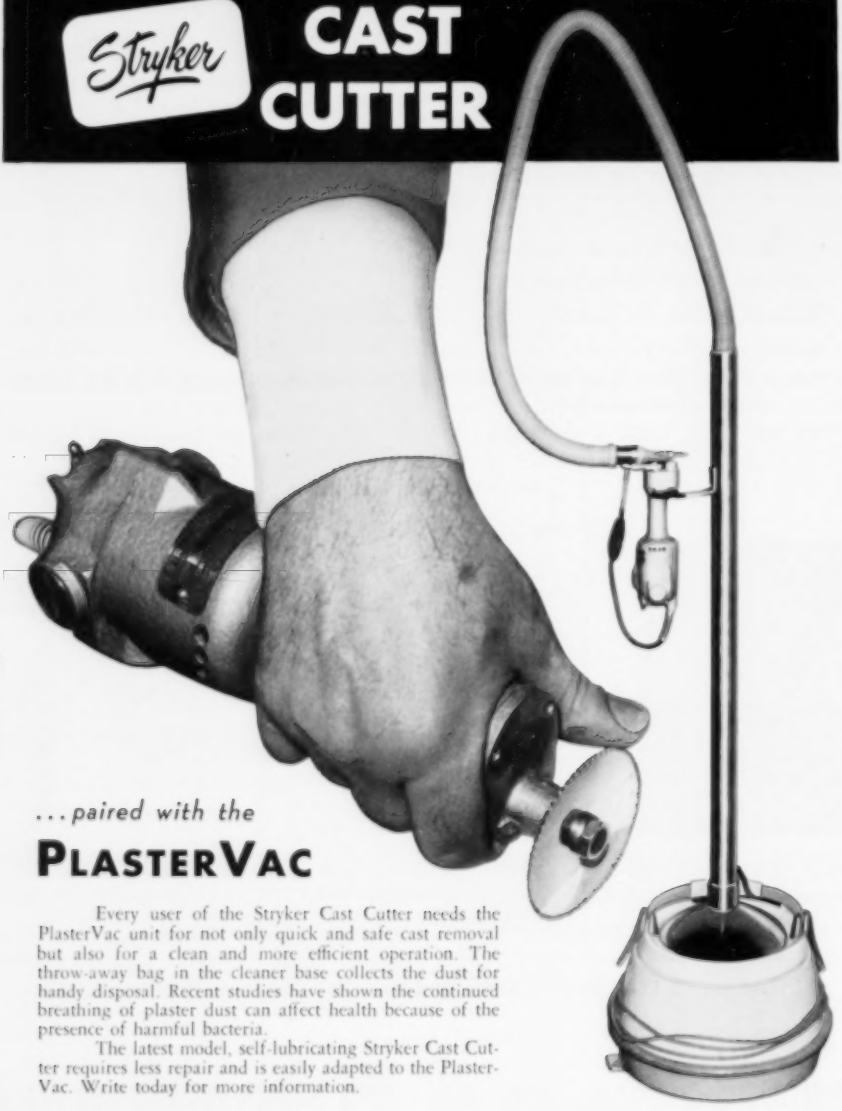
(Brand of Steroid – Vitamin Combination)

for matrix formation

In answering advertisements, please mention *The Journal of Bone and Joint Surgery*.

NOW... time saving, sanitary cast removal with

Stryker CAST CUTTER



...paired with the

PLASTERVAC

Every user of the Stryker Cast Cutter needs the PlasterVac unit for not only quick and safe cast removal but also for a clean and more efficient operation. The throw-away bag in the cleaner base collects the dust for handy disposal. Recent studies have shown the continued breathing of plaster dust can affect health because of the presence of harmful bacteria.

The latest model, self-lubricating Stryker Cast Cutter requires less repair and is easily adapted to the PlasterVac. Write today for more information.

Stryker

SURGICAL AND HOSPITAL EQUIPMENT

Orthopedic Frame Company

420 ALCOTT STREET • KALAMAZOO, MICHIGAN

Distributed in Canada by: Fisher & Burpe, Ltd., Winnipeg

Exclusive Agent for Export: Schueler & Co., 75 Cliff St., N. Y.

to control nausea,
vomiting, or retching—
before, during, or
after surgery

Compazine*

- hypotensive effects are minimal and infrequent—even during spinal anesthesia
- may be administered I.V., as well as I.M., orally, or rectally
- minimal potentiation of C.N.S. depressants
- pain at the site of injection has not been a problem

For immediate effect: 2 cc. Ampuls (5 mg./cc.) and 10 cc. Multiple dose vials (5 mg./cc.).
Also available: Tablets, Spansule† sustained release capsules, Suppositories and Syrup.

Smith Kline & French Laboratories

*T.M. Reg. U.S. Pat. Off. for prochlorperazine, S.K.F. †T.M. Reg. U.S. Pat. Off.

Lock the Bone with Dynamics

SUMMARY OF BASIC TECHNICS*

The RUSH® MEDULLARY PIN

PAT. NO. 2,579,968

COMPLEX ANKLE FRACTURE

The pins here were straight when driven. Curves were produced by intraosseous pressures to give stable fixation without need for external splinting.

SINGLE PIN

Indicated when both fragments have substantial length.

STRAIGHT PIN: Areas indicated in black.

CURVED PIN: Shafts of humerus, femur and tibia. Resists muscle angulating force by three point pressure.

Humerus Shaft

Femur Shaft

Tibia Shaft

* Rush, Leslie V.: Fracture Problems, Mississippi Doctor, Vol. 36, No. 5:115–118, Oct., 1958.

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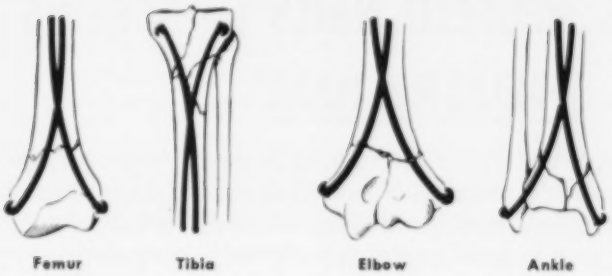
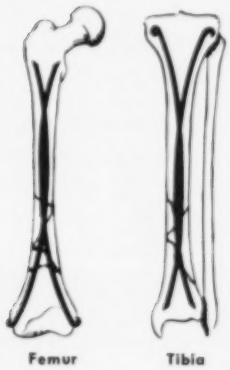
DOUBLE PINS

SIMILAR ANATOMIC AREAS

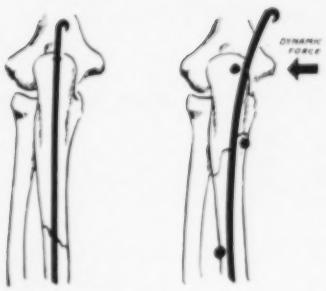


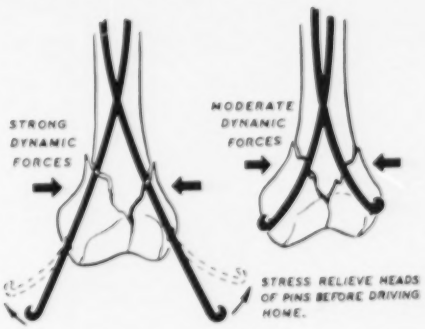


COMMINUTED FRACTURES

Similar Problems: Closed pinning best. Relatively good bone length can be maintained.

STRESS RELIEF OF HEADS





Pin inserted through end of bone exerts no dynamic force. Stress relief not necessary.

Pin inserted through side of bone is forced into curve. Result: Strong dynamic force with three point pressure. Head of pin can sink into bone unless stress relieved.

WRITE FOR INFORMATION
Exclusive Manufacturers of
RUSH MEDULLARY PINS AND INSTRUMENTS
Publishers of
"ATLAS OF RUSH PIN TECHNICS"
by LESLIE V. RUSH, M. D.

THE BERIVON *company*
MERIDIAN, MISS.

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FOR GREATER STRENGTH AND SAFETY—

DEMAND GENUINE **NEUFELD NAILS** *and* **SCREWS**

—IN **NEUTRILIUM®**

NEUTRILIUM® is the most non-corrosive metal known to science. Its proven super-strength lends an assurance of permanence to internal fixation of the trochanteric area. This neutral, non-magnetic, homogenetic alloy is entirely inert and therefore compatible with human bone or tissue, remaining unaffected by body chemistry.

NEUFELD BONE SCREWS — of *NEUTRILIUM®* — are cold forged and, unlike other metals, appear to be unbreakable under maximum human pressures. Heads will not twist off during application or in actual use.

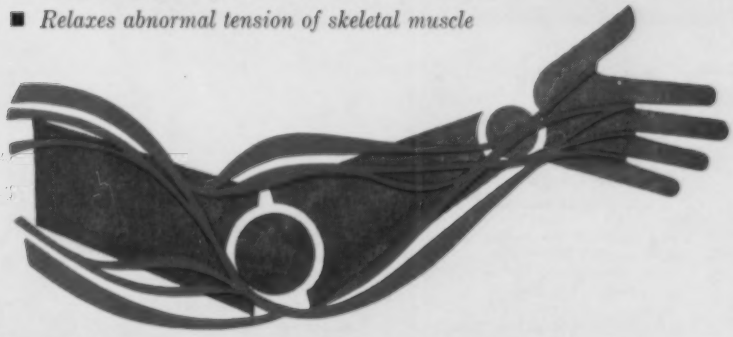
GENUINE NEUFELD NAILS and SCREWS — of *NEUTRILIUM®* — made only by MEDICAL RESEARCH SPECIALTIES, Loma Linda, California, are sold nationally by leading surgical and orthopaedic supply dealers.

NEUTRILIUM® is a registered Trade Name of Medical Research Specialties.

NEUFELD FEMORAL NAIL PLATE
Used for internal fixation of intertrochanteric and subtrochanteric fractures.
Write for descriptive literature
MEDICAL RESEARCH SPECIALTIES
Loma Linda, California

now...a new way to relieve pain and stiffness in muscles and joints

- *Exhibits unusual analgesic properties, different from those of any other drug*
- *Specific and superior for relief of* SOMAtic *pain*
- *Modifies central perception of pain without abolishing natural defense reflexes*
- *Relaxes abnormal tension of skeletal muscle*



SOMA™

N-isopropyl-2-methyl-2-propyl-1, 3-propanediol dicarbamate

In back pain, bursitis, sprains, strains, and bruises, whiplash and other traumatic injuries, inflammatory and degenerative muscle and joint complaints.

RAPID ACTING. Pain-relieving and relaxant effects start within 30 minutes and last for at least 6 hours.

NOTABLY SAFE. Toxicity is extremely low. No effects on liver, endocrine system, blood pressure, blood picture or urine have been reported. Some patients may become sleepy on higher than recommended dosage.

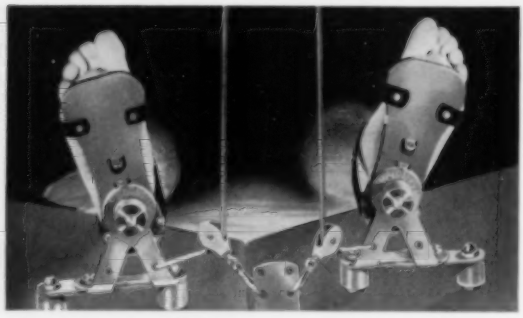
EASY TO USE. Usual adult dose is one 350 mg. tablet 3 times daily and at bedtime.

SUPPLIED: Bottles of 50 white sugar-coated 350 mg. tablets.

Literature and samples on request.

WALLACE LABORATORIES, NEW BRUNSWICK, N. J.

BOWEN FRACTURE APPLIANCES—
GREAT AIDS TO BETTER SURGERY



LEG EXERCISER SETS

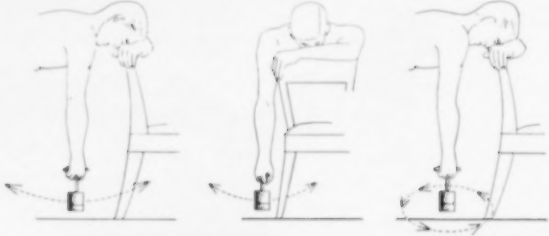
Designed to assist in passive abduction after cup arthroplasty, rehabilitation of paraplegics, and many other cases requiring weight controlled exercises.

- Rigid Construction—Relatively Light in Weight
- Moves Freely on Ball Bearings in All Directions
- Protractor Adjustment for Foot Angle Control
- Weight Attaching Eyes at Different Levels
- Foot and Heel of Exerciser Covered with Foam Rubber
- Exercising Board 14" x 48", Hinged at Center and Angled to Approximate the Arc Scribed by the Legs

ORMANDY PENDULUM EXERCISER

To Prevent Frozen Shoulder

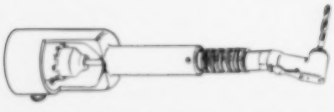
An excellent means to RELIEVE MUSCLE SPASM and PAIN of the shoulder girdle by traction in order to increase the ARC OF MOTION of the scapulo-humeral joint.



Efficient Method of Exercising for Shoulder—Joint Injuries

To Prevent Frozen Shoulder

The compact size of the Pendulum Exerciser will make it possible to increase the arc of motion without hitting the leg of the patient.



ANGLE DRILL ATTACHMENT

For Luck Bone Saw and Stryker Drill

Designed Especially for the Bankhart Operation

Excellent for bone surgery at difficult angles and in restricted areas requiring use of drills, curetting burrs, slotting burrs. Rigidly constructed, light in weight. Entire unit may be sterilized. Two 3/32 inch diameter High Speed Drills supplied with each attachment.

Easily attached to Jacobs chuck with key.

A hole in the end of the drill bit is provided so that the suture can be threaded and pulled through with the extraction of the drill.

GONIOMETER—
Pocket Size
Anodized Aluminum

A Pocket Size instrument with calculation flexibility allowing complete angle determination in degrees.

Produced from aluminum, anodized and dyed black, with white-lead-filled dial and indications permitting full penetration of radiation and screening a permanent secondary shadow of measurement on the film for consultations and computations.

BOWEN & COMPANY
INC.

P. O. Box 5818
BETHESDA, MARYLAND

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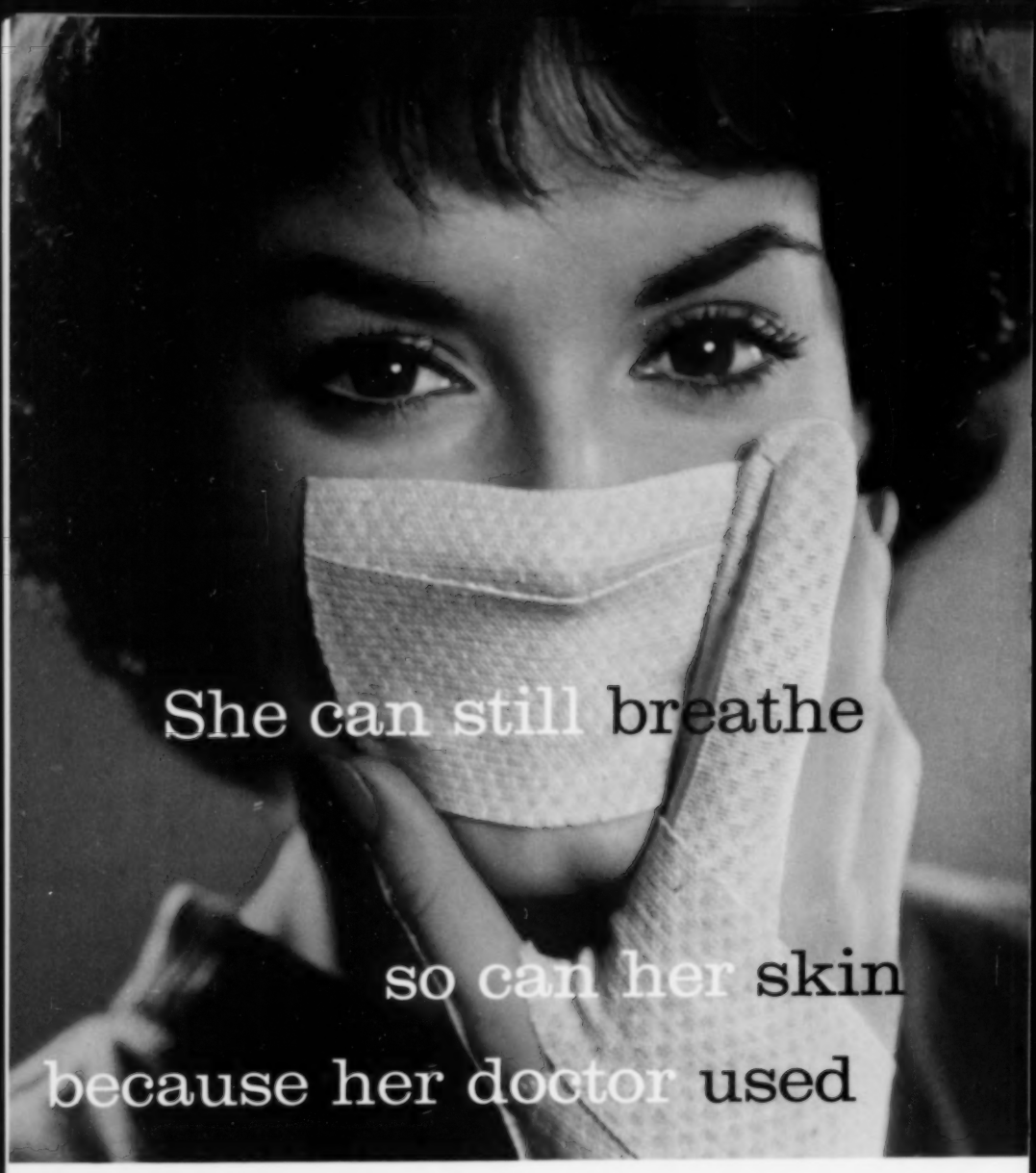
NOW

POROUS TAPES

PERMIT THE SKIN

TO "BREATHE"



POROUS

Available Now in
1", 2", 3" and 4" widths

Products bearing Red Cross trademark have no connection with American National Red Cross.

© J&J 1959

ZONAS TAPE TOO IS POROUS!

Now, a new J&J process imparts the same *porous* feature to ZONAS "regular" (non-elastic) adhesive tape.

A unique method of coating creates hundreds of porelike holes in the adhesive mass which allow perspiration to escape from the skin.

Because it too, permits the skin to "breathe", ZONAS *porous* tape minimizes a significant cause of irritation and is more comfortable for the patient.

ZONAS® Porous Adhesive Tape

NOW AVAILABLE in 12" x 10 yd. rack rolls in the following widths:
½", 1", 1½", 2", 3", 4" and assorted.

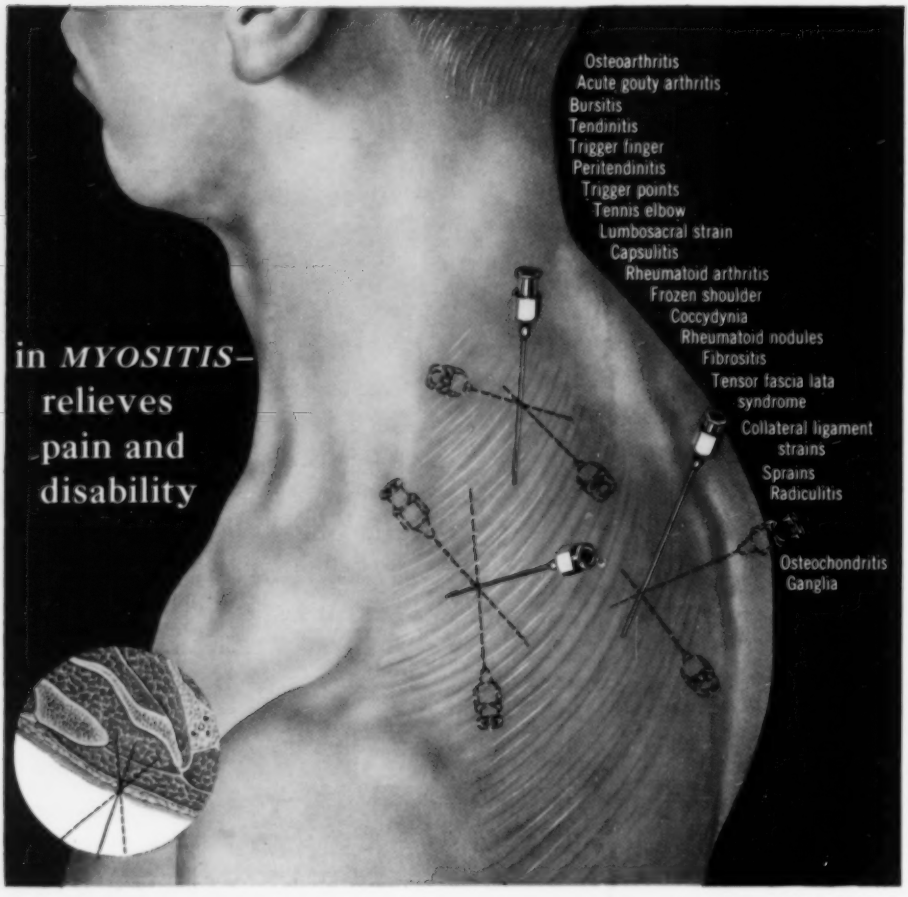
Johnson & Johnson

HELPING THE HANDS THAT HEAL

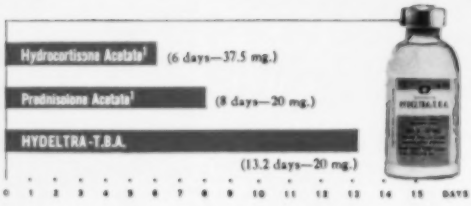
HYDELTRA® -T.B.A.

(Prednisolone tertiary-butylacetate, Merck)

for relief that lasts—longer



Anti-inflammatory effect lasts longer than that provided by any other steroid ester


Hydrocortisone Acetate[1] (6 days—37.5 mg.)
Prednisolone Acetate[1] (8 days—20 mg.)
HYDELTRA-T.B.A.
(13.2 days—20 mg.)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 DAYS

Dosage: the usual intra-articular, intra-bursal or soft tissue dose ranges from 20 to 30 mg. depending on location and extent of pathology.

Supplied: Suspension "HYDELTRA"-T.B.A.—20 mg./cc. of prednisolone *tertiary*-butylacetate, in 5-cc. vials.

MERCK SHARP & DOHME
DIVISION OF MERCK & CO., INC.
PHILADELPHIA 1, PA.

VOL. 41-A, NO. 4 JUNE 1959

The Journal of
Bone and Joint Surgery

American Volume

Primary Tendon Repair

EDITORIALS

One of the common problems encountered in the emergency room is that of divided tendons in the hand. Their very presence in a wound seems to demand that something be done. There is always fear that if repair is not undertaken the surgeon will be accused of negligence. Under these circumstances repair is too often undertaken with poor preparation of the patient by a surgeon with inadequate experience, with inadequate anaesthesia, and without the advantage of a bloodless field. It is rare indeed that proper instruments and suture material, adequate assistance, good light, and proper aseptic conditions are available in the ordinarily equipped emergency room. The distal stump of the divided tendon usually appears in the wound or can be brought into view by flexing the fingers. What is more natural than to seek the proximal stump above? The location of the proximal stump, however, and its exposure present real problems. The uninitiated will usually attempt to grasp it with forceps and pull it down into the wound. This is frequently not possible, and in order to locate it, a longitudinal incision is made over its course. The tendon, of course, is then easily found and brought down for suture. If by chance, the tendon stumps can be brought into the wound, forceful retraction is required for exposure, with resultant damage to the wound borders. Wounds at the wrist will usually present many divided tendons and nerves which may be difficult for the uninitiated to identify. It not infrequently occurs that nerve and tendon ends are sutured together. Oftentimes even the extent of the damage is not appreciated and re-exploration of the wound presents a tangled mass of nerves and tendon ends which may be sutured *en masse*. In wounds of the palm, excessive hemorrhage will make the identification of structures difficult, particularly if the surgeon fails to apply a blood-pressure cuff to ensure hemostasis. Frantic efforts are then made to catch blood vessels, and nerve and blood vessel may be ligated together.

The patient himself is often not properly assessed as to his general condition; the condition of the wound may not be appreciated, and it may not be known what has been done about the wound previously. History as to the time at which the wound occurred and the possible amount of primary and secondary contamination may not be considered. If the wound is of the severe crushing nature, the overlying tissues may be badly damaged, open fractures may be present, and the skin be so severely crushed that it cannot be replaced. In more severe injuries the skin may actually be lacking, so that proper coverage over the site of nerve and tendon repair is not possible.

Obviously, tendon repair carried out under conditions such as the above is bound to be a failure. Faced with such unfavorable conditions, the surgeon should not attempt tendon suture. We cannot, however, judge the results of primary

tendon repair on the basis of procedures which have been carried out with inadequate facilities.

Conversely, in the hands of surgeons experienced in tendon surgery, certain very definite indications must be met before primary repair of divided tendons in the hand is undertaken. In the absence of these indications, even with adequate help, assistance and "know-how", primary repair is not done. What are these criteria which are essential to permit early primary tendon repair? The wound must be seen early. It is very rare indeed that tendon repair is carried out in a wound over eight hours old—usually, four to six hours are taken as the upper limits. The degree of primary contamination must be ascertained by obtaining an accurate history of the wound, when and how it was incurred, and what had been done to it before it is presented for treatment. In those instances in which potentially serious invasive contamination has taken place at time of injury, as, for example, in bites, primary tendon repair is never permissible. If the wound has not been properly dressed from the time of the accident, or if probing or fingering of the wound has been carried out elsewhere, it is assumed that serious secondary contamination has probably occurred, and that primary tendon repair is not indicated.

The nature of the wound itself is of importance. Sharp lacerated injuries with division of tendons permit primary repair, whereas crushing injuries with damage to the skin and often open fractures are seldom the ones in which primary repair can be carried out. In order to do primary repair it must be possible to secure proper coverage over the site of the repair, with adequate skin flaps and subcutaneous tissues. If such covering cannot be provided, it is not permissible to carry out tendon suture. The surgeon should have an experienced assistant, satisfactory anaesthesia, and proper instruments and sutures. He should work in a bloodless field, secured by means of a blood-pressure cuff. He should have some knowledge as to how tendons heal and how they should be repaired as well as adequate technical skill. Finally, the surgeon should know how to make proper incisions for exposure, should appreciate the gentle technique necessary in handling tendons, and should have the patience to carry out the necessary repair. With these criteria fulfilled, practically all surgeons agree that in most cases primary repair is permissible. Some differentiation is made between the flexor and the extensor tendons. In the main, the extensor tendons heal better and more surely than the flexors, and primary repair of the extensors is more likely to be successful than it is in the case of the flexors.

For injuries of the flexor tendons it is customary to divide the volar surface of the hand into various zones. With division of the flexor profundus distal to the insertion of the sublimis, there is general agreement that primary repair is usually permissible. In this zone it is sometimes necessary to advance the flexor tendon so that the site of repair does not lie within the fibrous digital tunnel. Division of tendons in the palm and in the wrist and forearm are, likewise, usually amenable to primary repair. There is a little disagreement as to whether both profundus and sublimis should be repaired. In these cases, the functional results seem to be very good even if only the profundus is repaired. However, many surgeons believe that both sublimis and profundus can be repaired in the palm and forearm.

There is some disagreement in regard to tendon division in the thumb, but it is not serious. In the main, it would appear that primary tendon repair in the thumb is permissible, but difficulty is encountered when the divided tendon is in the thenar eminence, where a great deal of hemorrhage may take place and the presence of the digital nerve ends may often make identification and repair of the flexor pollicis longus difficult.

The greatest disagreement, however, concerns the area which has been called *no-man's land*. This critical zone is where the two sublimis slips and the profundus tendon lie together within the narrow confines of the fibrous digital sheath. It extends from the proximal end of the flexor sheath in the palm to the site of

insertion of the sublimis tendons in the base of the middle phalanx. In this area, when only one of the tendons has been divided, primary repair is certainly not indicated. The real point of contention is what should one do if both the profundus and sublimis tendons are divided in this critical zone? This is a not infrequent location for tendon injury and an area where the temptation to carry out primary suture is very great. The position taken by possibly the majority of surgeons is that primary repair in this zone, even with all conditions favorable, should never be carried out. The wound should simply be cleansed and sutured and allowed to heal, and repair carried out as a secondary procedure later on, usually by means of a tendon graft. Other surgeons, however, believe that under favorable conditions primary repair may frequently be undertaken in this area with a good chance of success. They insist, however, that all the indications for primary repair be strictly observed, that the time since injury be not over four hours, and preferably not over two, that tissue damage in the wound be very slight and contamination minimal, that the wound be caused by a sharp, cutting instrument, and that immediately after injury it had been covered with a protective first-aid dressing. These surgeons stress, among other things, proper exposure of the tendon by physiological incisions, repair of the profundus tendon only, and removal of the sublimis. They stress also the removal of a window in the fibrous tendon sheath over the area of tendon repair to permit the healing tendon to come in contact with subcutaneous fatty tissue and not with dense fibrous sheath. This window also decompresses the tendon sheath so that circulation in the tendon is not hampered. Likewise, such repair must be carried out with very fine suture material in minimal amounts and by a technique of the greatest gentleness. Obviously, such patients require proper after-care.

Actually, there are very few injuries that conform to these rather strict criteria. If the criteria are not present, or if there is any doubt in the surgeon's mind as to whether or not this repair should be undertaken, it is best simply to cleanse and close the wound, to permit healing to occur, and to carry out repair as a secondary procedure later on by a tendon graft. There is, therefore, no large group of patients in whom the question of primary repair of the flexor tendons in no-man's land presents a real problem. The reports by Verdan of Lausanne, the paper appearing in this issue of The Journal by Kelly, and the reports by Bsteh indicate that primary repair of the flexor tendons is often a satisfactory solution from both an economical and functional standpoint. If only one operation is needed, it is certainly a much happier solution from the patient's standpoint.

I very much fear that we have taken a defeatist attitude toward primary flexor-tendon repair. Obviously, even with proper indications, any type of tendon repair is sure to fail with improper technique and lack of skill. Primary tendon repair is likewise sure to fail when the wound is not suitable for it. One must admit also that tendon-grafting carried out with poor indications, without proper training, and under adverse conditions certainly is not successful either. Those who advocate secondary repair of these injuries advocate their repair by tendon-grafting, but they imply that this grafting will be carried out by one skilled in this type of surgery.

What is needed here is not a different technique for introducing sutures but the careful, gentle technique of the plastic surgeon. With his manner of handling tissues with the greatest gentleness and with meticulous hemostasis, we can look forward to successful primary repair even in the critical zone.

Michael L. Mason, M.D.

WHY TENDON REPAIR?

Why should a severed tendon be sutured? There is only one reason: to restore an essential function to the part the tendon serves.

When should a severed tendon be sutured? At a time when, considering the condition of the wound and the facilities available, it is the decision of the surgeon that repair can be accomplished without danger to the over-all function of the hand.

Use of the word *primary* as applied to the repair of severed tendons implies a need for immediate repair and hides the fact that two distinct problems are present: first a wound, and second a loss of tendon function. When faced with a wounded organ showing loss of function, we must distinguish between treatment of the wound and treatment of the loss of function. In primary care, our first aim should be to deal with the wound. This is the insult to the organ, the break in its protective covering, the solution of continuity, the tearing, stretching, and contusing, and the contamination with potentially destructive organisms. Our purpose of treatment is first to protect this organ from infection and to prevent the added disability that follows the prolonged uncontrolled swelling, oedema, and cicatrix caused by the traumatizing force. Only when this aim of our first treatment, this complete protection, with uncomplicated healing can be accomplished with practical certainty, are we justified at this point in time in considering surgical treatment of the functional loss. One might summarize the immediate care of the injury by the word *protection:* protection of the wound from infection, protection of the part from added disability.

Assuming the wound to be small in area, sharp and incised in type, and clean in character, and that as the result of proper wound treatment, prompt and reactionless healing will occur, there is no reason why the lost function cannot be cared for at the same time that the wound is treated. There must be proper indications for such repair, and the factors of good operating-room facilities, adequate assistance, necessary instruments, and experience must be present. Lacking either the assurance of the results of the wound treatment or the proper facilities, our attention should be focused on the protective phase of the care of the wound.

What are the indications for tendon repair? If the severance has not resulted in loss of function, surgery is wasted time and effort. Division of the palmaris longus results in an imperceptible loss of function. If the severance of a tendon results in loss of a minor function, but the repair would result in the loss of a more important function, the greater disability is then cheirogenic. For example, assume a severance of the profundus tendon in the middle segment of the finger with the proximal end of the tendon retracted into the palm. The loss of function here is lack of flexion of the distal joint and lack of stability of pinch. Direct repair with attempted rethreading of the tendon through the intact sublimis will almost always result in some loss of function of the sublimis and thus limit the flexion of the middle joint. Whereas originally, there was only loss of a simple function, that is, pinch, the patient now has impaired function of a whole finger. The disability has been compounded by the surgery. A reconstruction, such as a tenodesis or arthrodesis of the distal joint aimed at restoring the original lost function, would not have jeopardized the remaining function of the finger.

If the healing process which accompanies a repaired tendon involves the surrounding parts, interfering with a contiguous normal structure subserving a more important function, then again surgery is meddlesome. A sublimis tendon severed in the proximal segment of the finger should not be repaired. The loss of function is negligible, and the normal cicatricial reaction following an attempted repair will interfere with the gliding of the intact adjoining profundus. There will be loss of function of the digit as a whole. Without repair, the finger can be extended and flexed completely. After attempted repair, neither motion will be complete.

When a tendon is severed in company with severe skeletal damage, especially in the digits, the strong pull of the repaired tendon may cause angulation deformity or delayed union of the bone. It is better to build a good solid framework for the machine before putting in the moving parts.

It has long been recognized that the healing process in a tendon varies with

the type and location of the tendon and that to be successful and restore function to this gliding mechanism, the most exacting care and skill of the surgeon are required. Therefore, if less than ideal conditions are present, and an adequate operating room, anaesthesia, proper instruments, and technique are lacking, the result will be less than ideal. Since secondary repair, when repair is indicated, offers as much restoration of function as primary repair and, in certain conditions, other elective procedures offer even more, surgery performed under less than the proper conditions is risking the loss of function.

There is little evidence that repair of a tendon at the time of injury results in any better function than a properly done secondary repair or reconstruction. On the contrary, there is ample evidence that in some instances more normal function results if repair is not done. A simple example is a severed profundus tendon near its insertion. Repair of the divided tendon will usually give stability but because of the scarring at the tendon junction so near the distal joint capsule, little active voluntary flexion is possible. If, however, the tendon is advanced and reinserted into the bone, a more normally acting distal joint results. In cases of severance of both flexor tendons in the finger, secondary reconstruction by a free graft, if done properly, will result in a higher percentage of satisfactory function than direct repair.

When the treatment of the wound has been accomplished and healing is complete, there remains only the problem of the lost function. At this time when, as Steindler says, tissue equilibrium has been reached and there is morphological quiet, the surgeon is faced only with the one problem of restoring lost function. His choice is not restricted and he can do what is best for the return of function of the organ. His procedure becomes elective and he can concentrate on the best way to restore function and can accomplish it with minimal disturbance to the other parts. Here, instead of repair of the tendon, judgment may dictate an alternative procedure such as a transfer, advancement, grafting, or stabilization.

Perhaps it would be well to discourage the use of the phrase *primary tendon repair*. It would be better to entitle such studies, "Care of the Injured Hand". We could then concentrate upon the real problems; first the protection of the wound, the protection of the hand from added disability, and, finally, the restoration of function to the hand—this "most marvelous mechanism of exquisite design and delicate sensibility".

Joseph H. Boyes, M.D.

THE MANAGEMENT OF TENDON INJURIES

So much emphasis has been placed on the various techniques of tendon repair that the reader is apt to get an erroneous impression of the subtleties of the management of tendon injuries. It would seem that the whole problem comes down to the fact that if the danger of infection does not contraindicate tendon repair and the tendon has not been severed in the flexor sheath at the base of the fingers, then primary tendon anastomosis should be performed. Otherwise, we should close the wound and later do a tendon graft or perhaps a delayed tendon suture under certain circumstances. This is a great over-simplification of the problem.

It is essential that we bear in mind the natural reparative ability of certain tendons which are surrounded by paratenon and the excellent results which may be obtained by splinting alone. There are, of course, tendons with no worth-while function which need not be repaired, such as the palmaris longus and the plantaris. There are also tendons which should not be repaired because they will repair themselves, perhaps better than the surgeon, such as the common toe extensors and the extensor hallucis longus. Any one who has attempted a Jones suspension on

many occasions will appreciate the tenacity with which the extensor hallucis longus strives to revert to its original function. If the severed toe extensors tendons are left unrepaired, there is no functional disability and perhaps the only way we can get a disability is to attempt surgical repair and thus limit their excursion and produce a hammer-toe deformity. Lacerations or avulsions of the extensor aponeurosis of the fingers heal satisfactorily if the finger is splinted in a position of maximum relaxation of the tendon. Divisions of the extensor tendons over the dorsum of the hand are easy to repair surgically, but if surgical repair seems contra-indicated, as in contaminated wounds or human bites, proper splinting will generally lead to functional repair of the divided tendon without the added danger of tenorrhaphy.

It is even more important in complex wounds that we realize that tendons of secondary importance should not be repaired if their repair might compromise the result in more important tendons. In a lacerated wound over the volar aspect of the wrist with division of all the tendons, as well as the median and ulnar nerves, the structures of primary importance are the nerves, the flexor pollicis longus, and the flexor digitorum profundus tendons. We can consider that the digital sublimi and the wrist flexors are of secondary importance. If all twelve tendons and both nerves were sutured over the volar aspect of the wrist in that small confined space, nothing but a great homogeneous mass of scar tissue will be likely to result with no functional activity on the part of any tendon or nerve. The flexor digitorum sublimis tendons should seldom be repaired, particularly in complex wounds. Gravity will provide wrist flexion but more important, since the flexor carpi ulnaris and flexor carpi radialis are tendons in paratenon they will usually repair themselves in a functional manner. Fibrosis is the enemy of successful nerve tenorrhaphy and limits tendon excursion. We should, therefore, attempt repair with the object in mind of limiting fibrosis as much as possible. In particular, the flexor carpi ulnaris should seldom, if ever, be repaired and when it is severed along with the ulnar nerve, even if only these two structures are damaged, I would resect enough of the ulnaris tendon to make sure that the neural anastomosis was surrounded by loose areolar tissue, giving it a more favorable environment. Invariably, by the time that nerve regeneration is complete, the flexor carpi ulnaris muscle will have become functional and the examiner will be unable to detect any loss of function.

On the dorsum of the wrist, however, a different problem exists in that here, extension of the wrist is of primary importance as is abduction of the thumb, whereas extension of the fingers and thumb is secondary. Here, first consideration must be given to providing good extension of the wrist and abduction of the thumb. The extensor carpi radialis brevis is the most important extensor muscle of the wrist and the abductor pollicis longus is the most important muscle on the dorsoradial aspect of the thumb. Extension of the fingers and thumb can be restored later or given a simple mass extension action by providing one or two motors to power the extension. Gravity aids greatly in extending the fingers and a functional tenodesis will give a result which is surprisingly good. Certainly, on the dorsum of the wrist when all tendons are divided one should not attempt to repair every one. On the contrary, in a wound of this nature, one should provide the patient with his basic needs so far as possible and accept the fact that sometimes simplification of the mechanical unit and elimination of certain moving parts is necessary since otherwise none of the parts may function.

S. Benjamin Fowler, M.D.

Primary Tendon Repairs

A Study of 789 Consecutive Tendon Severances *

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Hauge, in a study of 726 tendon injuries sutured in a general surgical service, gave us an accurate picture of the results to be expected when tendon repair is performed by personnel who lack particular interest in the special problems of hand surgery. Hauge concluded that primary tendon repairs in no man's land and the area distal to it should not be undertaken by the general surgeon and that patients with such injuries should be referred to a hand surgeon for secondary repair.

This study was made to determine if Hauge's pessimistic outlook is justified, or if the referring of these cases to a service primarily concerned with hand injuries improves the prognosis to the point that primary tendon suture within the area of the annular ligament and distally should be encouraged, or should be emphatically condemned. I hope to draw attention to the poor results occurring after extensor-tendon repairs in certain anatomical locations.

This study comprised 706 patients with 1,018 severed tendons treated from September 1952 through June 1957. The patients were all treated in the Division of Plastic Surgery under the supervision of Dr. Robert H. Clifford or myself, and all modern therapeutic advantages were available. Seventy-nine patients having eighty-six tendon lacerations were discarded from the study since they had incomplete severances; these tendons were repaired, but it was impossible to determine whether the results were due to, or in spite of, surgery. Severed wrist tendons were not included because repair was performed jointly with the Orthopaedic Service and there was no consecutive follow-up. The remaining 556 patients with 789 severed tendons, treated by a single service, will be discussed in detail (Table I).

METHOD OF STUDY

Several years ago a punch-card system was established for the study of tendon repairs, in which data describing the patient, injury, methods of repair, anaesthesia, after-care, and results were recorded. The data were obtained by all members of the service but were indexed by one person for uniformity. A breakdown of the recorded material follows:

The age, race, sex, and status (industrial or private) of the patient were noted. The data on the injury specified the involved hand and digits, and the level of injury and whether it was open, closed, flexor, extensor, clean, dirty, sharp, or crushing. Accompanying nerve injury, fracture, vascular state, and loss of skin requiring graft or pedicle flap or both were also noted. Whether treatment was primary or delayed, and the length of time from injury until treatment, experience of the surgeon, and method and material of suture were recorded. The type of anaesthesia, whether general, brachial block, or local, was noted. The after-care, including antibiotics, immobilization, physical therapy, and secondary procedures, was recorded. The results were graded as excellent, good, or poor, and the presence of scars, pain, or anaesthetic areas was noted.

* Read in part at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., January 3, 1958.

TABLE I

DATA ON 789 SEVERED TENDONS OF 556 HANDS

Tendon	Closed Injuries No. of Patients	No. of Injuries	Tendon	Open Injuries No. of Patients	No. of Injuries
Flexor	2	2	Flexor	218	380
Extensor	34	37	Extensor	302	370
Totals	36	39		520	750

TABLE II

METHOD OF SPLINTING AND RESULTS

Method	Open Extensors Results			Method	Closed Extensors Results		
	Excellent	Good	Poor		Excellent	Good	Poor
External	15 (7)*	7 (1)	2	External	1	0	0
Internal	18	10	5	Internal	14	5	3
Pratt	11	6	1	Pratt	8	3	3†
In distal interphalangeal joint	7 (2)	4	4	In distal interphalangeal joint	6 (2)	2 (2)	0

* Numbers in parentheses indicate the number of thumbs in each total.

† In two instances open repair of the tendon was not done.

Many variables which were initially a part of our study were eliminated because they were difficult to evaluate consistently; among these were type of exercise, time lost from employment, and motivation of patient to recover.

EVALUATION OF RESULTS

Results were determined by membrs of the service in 86 pr cent of the injuries, and by the referring physicians who were aware of the criteria in 13 per cent. Telephone contact and letter response were each relied on in 0.5 per cent of the cases, but only if the result could be unequivocally determined. The results in two patients who died and others who were not located were classified as indeterminate; these results will appear in various subdivisions, such as level of injury, but will not be included in the percentage of results.

The results of the patients with flexor-tendon injuries were determined according to criteria similar to those used by Kyle and Eyre-Brook and for the extensor-tendon injuries by criteria of Miller with modification.

Flexor

Results were considered *excellent* when the patient was able to bring the tip of the pulp of the digit to within one-half inch of the distal palmar crease.

Results were judged *good* if the ability to bring the tip of the pulp of the digit to one and one-quarter inches of the distal palmar crease was demonstrated.

Results were considered *poor* if the patient was unable to bring the tip of the pulp of the digit to within one and one-quarter inches of the distal palmar crease.

Movement in the thumb was also graded by these criteria because the ability to bring the tip of the pulp of the digit to the distal palmar crease depends on successful repair of the flexor pollicis longus.

Some loss of extension has been common after repair of injuries of the flexor tendon of the finger in our patients. A flexion deformity of 10 degrees from 180 degrees at the proximal interphalangeal joint and 10 degrees at the distal in-

terphalangeal joint was considered functionally insignificant. Flexion deformity exceeding this would downgrade the result. On the average, in hands with excellent results there will be from 75 to 100 per cent range of motion; good, 50 to 75 per cent; and poor, 50 per cent or less.

Extensor

Results were graded *excellent* if the patient had not lost more than 5 degrees of motion at each of the interphalangeal joints; good, if the loss was not more than 10 degrees; and *poor*, if the loss of extension exceeded 10 degrees.

37 CLOSED EXTENSORS
Tendon Repair

	No.	%
DISTAL		
Excellent	15	65
Good	5	22
Poor	3	13
PROXIMAL		
Excellent	3	50
Poor	3	50
BACK OF HAND		
Excellent	2	66
Poor	1	34
EXTENSOR RETINACULUM		
Excellent	5	100

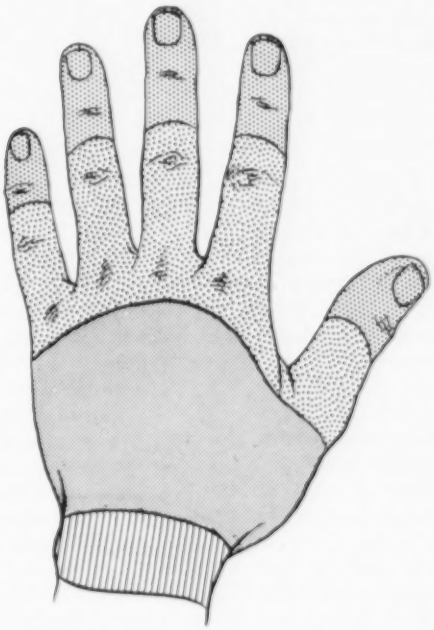

CHART I

The percentages are calculated on the basis of thirty-seven repairs with known results. There were no cases lost to follow-up. The results in repairs of the thumb and fingers are combined in this chart.

These criteria consider only the joints distal to the injury and of essentially normal opposing function. All results given are based on the outcome of the first tendon operation. When secondary operations improve the result, they will be mentioned in the text but not tabulated.

CLOSED INJURIES

There were two closed flexor-tendon injuries, one in an anomalous flexor. These will be considered under the appropriate flexor category.

There was a favorable outcome in 81 per cent of the thirty-seven closed extensor injuries (Chart I).

There were five cases of so-called drummer's palsy with extensor pollicis longus rupture, and the results were excellent in two after simple suture and in three after extensor indicis proprius transfer.

TABLE III

GENERAL FEATURES OF THE OVER-ALL OPEN EXTENSOR GROUP (370 SEVERANCES)

	Per cent		Per cent		Per cent
White	70	Right	72	Sharp	64
Negro	30	Left	28	Crushing	36
Male	95	Clean	54		
Female	5	Dirty	46		

Level of Injury		Digit Involved		Age by Decade	
	Per cent		Per cent		Per cent
Carpal tunnel	26	1	16	1	3
Palm	13	2	34	2	3
Proximal phalanx	32	3	25	3	23
Distal phalanx	22	4	4	4	27
		5	21	5	22
				6	11
				7	10
				8	1

There were six cases of boutonnière deformity; excellent results were obtained in three. Results were excellent in the patients treated early in whom simple suture or reinsertion was possible. The three injuries of long standing were improved but range of motion was definitely poor.

Mallet-finger injuries were treated by internal fixation in all but one patient. An excellent result was obtained in one patient treated by an external splint. Internal splinting by Kirschner wires, as suggested by Pratt, was used in fourteen injuries; and eight injuries (four digits involved were thumbs) were treated by fixing the distal interphalangeal joint only. Fixation of only the distal interphalangeal joint produces fewer excellent results but it will consistently produce good results. Excellent results with a Kirschner wire inserted into only the distal interphalangeal joint consistently resulted in a loss of approximately 5 degrees of extension; the Pratt wire technique produced results with no loss of extension. In spite of the small loss of extension, I feel that the use of the Kirschner wire in the distal interphalangeal joint only is preferable for middle-aged and elderly patients since there is the advantage of not jeopardizing the proximal interphalangeal joint (Table II). Immobilization in this group lasted four or five weeks in 72 per cent of the injuries. Earlier removal of the wire by design or accident was associated with less successful results. It was necessary to remove two pins because of infection around the pin. In this group only, there was a significant number of female patients (29 per cent).

In general, extensor repairs in the thumb are more satisfactory than those in fingers. In this particular small group, however, the thumb repairs had the same percentage of excellent, good, and poor results (Chart I).

OPEN SEVERANCES

Extensor

As indicated, the criteria for determining results are arbitrary, for an effort was made to find some correlation between results and surgical effort rather than the functional quality of the finger. Repairs that are unsatisfactory in regard to function do not exceed 3 per cent of the total. The general characteristics of the group are indicated in Table III. The levels of injury will be considered separately, and their variance with the entire extensor group will be noted if significant.

Suturing the tendons with 0000 multifilament stainless-steel wire, double-

armed with ski-cutting needles has been the surgical technique used for the repair of extensor tendons. The needles can easily be straightened or bent to suit the demands of the suturing. The stitch used is the second method described by Bunnell for buried silk. The needles are passed simultaneously to avoid damage to the previously inserted filaments. A fluffed-gauze and elastic compression dressing, incorporating a splint, is applied as the initial dressing. The involved digits are kept in the splint in moderate extension for four weeks. The splint is worn for one additional week except during daily periods of passive exercise.

370 OPEN EXTENSORS
Tendon Repair

	Thumb		Lesser Fingers	
DISTAL	No.	%	No.	%
Excellent	9	90	31	55
Good	1	10	16	29
Poor	0	0	9	16
PROXIMAL				
Excellent	24	69	63	72
Good	8	23	8	9
Poor	3	8	16	19
BACK OF HAND				
Excellent	0	0	37	77
Good	1	25	11	11
Poor	3	75	0	0
EXTENSOR RETINACULUM				
Excellent	56	97	5	33
Good	2	3	7	57
Poor	0	0	3	20

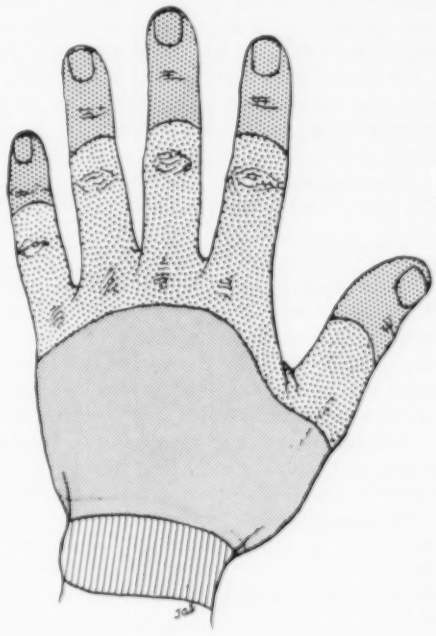

CHART II

The percentages are calculated on the basis of 314 repairs with known results. The results in thirty-six repairs are not known.

During the fifth week, active and passive exercises are begun and the splint is discarded. I generally utilize formal physical therapy for about three weeks in the group with extensor-tendon injuries.

Level of the Extensor Retinaculum

At this level, there was a high percentage of injuries to the left hand (28 per cent) and an uncommonly high percentage of thumb injuries (64 per cent). The incidence of infection was higher here than in the over-all extensor group, all occurring in hands with good results.

The technique of repair was the same as that indicated in the over-all extensor group except that the appropriate extensor retinaculum was unroofed to allow free excursion of the repaired area of the tendon (Chart II).

There were fifty-six thumb-extensor repairs in this group, of which there were excellent results in 95 per cent in spite of multiple complications. Comparison of the group in which the results were poor with that in which the results

were excellent and good revealed little difference in the injuries. There were eleven fractures and thirteen crushing injuries equally distributed among the various categories. The experience of the surgeon had some bearing on the results since those repairs done by attending surgeons were 96 per cent excellent; by experienced residents, 92 per cent excellent; and by less experienced residents, 74 per cent excellent. Injuries to this area and to the back of the hand are not as critical as those in the other tendon groups, and yet the experience of the surgeon has a definite effect upon the outcome. This factor assumes greater importance in the more critical tendon injuries.

Back of Hand

This group does not vary significantly from the over-all extensor group in regard to the various factors listed in Table III. The surgical handling was the same as that outlined for the over-all extensor group. There were four thumb injuries at this level; the result was good in one, and poor in three (Chart II). In the group with poor results there were eight secondary procedures, principally scar revision and flap procedures to obtain satisfactory covering for the tendon repairs, which then allowed all the patients operated on to have results judged good.

The comparison between the group with excellent and good results and that with poor results shows no significant difference in the severity of the injury.

Proximal

This group is comprised of patients who had injuries from just proximal to the extensor hood to just distal to insertion of the central slip into the middle phalanx. This area is a rough projection of the annular-ligament area of the flexor surface onto the dorsum of the hand. This places the extensor hood, the lateral bands, and the central slip in a single area, which can present surgical problems exceeded only by flexor injuries in the area of the annular ligament.

The patients in this group do not vary significantly from those in the over-all extensor group except for having a slightly higher incidence of injuries caused by sharp objects; there is a slightly lower incidence of female patients.

Surgical handling is similar to that outlined for the over-all extensor group with regard to splinting and after-care but there are a number of special considerations. The three major components of the extensor complex are examined and repaired anatomically. It is unwise to rely on functional tests in this area owing to the late-developing imbalance from overlooked injuries to these structures. The extensor hood must be repaired with 00000 monofilament wire; failure to do so results in the extensor communis snapping off the head of the metacarpal in flexion. To a lesser extent, there is loss of full extension because the communis tendon in the displaced position can extend to its insertion in a more nearly straight line with consequent shortening of its functional length. Simultaneous injury of the hood and extensor communis creates a problem in repair because the repaired tendon and hood heal in one scar. This results in a loss of excursion of the communis and also prevents the normal shift of the extensor complex during intrinsic-muscle action. For this reason I consider it unwise to repair the two structures simultaneously unless the repaired areas of each can be separated by splinting in some appropriate position. The hood can be repaired at a later date. When the central slip of the communis is repaired, special care is taken not to free large portions of the tendon and interfere with its delicate gliding mechanism beneath. Where it is ruptured from the middle phalanx it is reinserted into the bone of the middle phalanx with a wire suture placed in small drill holes. The lateral bands are repaired with multifilament 0000 wire sutures. The extensor expansion is also repaired; usually 00000 nylon sutures suffice for this repair. The failure to repair any of the structures mentioned distorts the alignment of the remaining tendon element, causes excessive length of

the tendon healed by scarring, or results in adhesions between the gliding portions of the extensor mechanism and the overlying and underlying structures. Since there is a limited amplitude of excursion available in this area to accomplish a rather large range of motion, these adhesions lead to an unsatisfactory result. This problem is further complicated by the frequent occurrence of fractures in association with the tendon injury. I generally rely on closed reduction or, more properly stated, reduction without the use of any internal fixation. The fracture must be exactly reduced and maintained. The position selected for splinting is one that will most exactly maintain the fracture rather than some position which would relax the tendon more satisfactorily. The slightest bowing of the proximal phalanx again causes difficulty owing to the shortening of the excursion of the extensor complex (Chart II).

The thirty-five tendon repairs in the proximal extensor group involved thumbs. The thumb does not have the complex extensor mechanism of the other digits, but the associated injuries were greater so that the results were comparable to those in the fingers (Chart II).

Comparison of the group with excellent and good results with the group with poor results shows a difference in the severity of injury as indicated by fifty-five complications in 105 repairs in the group with excellent and good results and twenty-three complications in eighteen repairs in the group with poor results. Fractures were four times as common in the group with poor results. These fractures were treated by intramedullary Kirschner wires in two cases in each group; the remainder of the fractures were treated conservatively. Experienced surgeons were present at a higher percentage of operations on patients with poor results, indicating the severity of the injury.

Distal

Injuries of the extensor tendons in the distal phalanges were more common in the left hand. All age groups were involved; however, there was a higher incidence of elderly patients than in the over-all extensor group (Table III). The incidence of infection and crushing injuries here exceeded that of all other groups.

Tendon repair was carried out with 0000 wire mattress sutures. Fixation of the distal interphalangeal joint with a Kirschner wire or of both the distal interphalangeal and proximal interphalangeal joints, as described by Pratt, was done in slightly more than half of the cases. The remainder were immobilized by external splints. The results of the various types of methods are shown in Table II; these numbers can be compared with the results in Chart II.

Comparison of the patients with excellent and good results with those with poor results indicates that the presence of avulsion fracture is detrimental to an excellent outcome. The presence of avulsion fracture, however, should not necessarily jeopardize the result, judging by the experience of others, if care is taken to reduce and maintain the fracture fragment accurately. The incidence of complications was three times greater in patients with poor results. Skin loss, requiring small flaps or skin grafts for closure, does not jeopardize the final result. In the patients treated earlier, Kirschner wires were left in position for as short a time as three weeks (33 per cent), since I was hesitant to leave the pins in joints for prolonged periods. External splints were used for an additional ten to fourteen days. Early removal of the wire and external splinting had no discernible effect upon the results. As previously mentioned, Kirschner wire fixing only the distal interphalangeal joint was not as effective in this series as the Pratt method. External splints produced poorer results in this limited group of patients. I tend to use an external splint in the more responsible patients who, I feel, normally have the most satisfactory results. It is my opinion that this factor, and the number of thumbs present in the group treated with external splints, adds significance to the poorer results.

Conclusions

It is apparent from a study of the preceding data that repair of extensor tendons is not a simple matter. The results in many series appear good because the repairs in the critical areas are lost in a profusion of tendon repairs in non-critical areas. Repairs of extensor-tendon injuries in the area of the extensor retinaculum on the back of the hand are rewarding if the complicating injuries are not severe. Premature discarding of splints was the major cause of poor results. As the surgeon progresses distally into the level of the extensor complex the injuries present surgical problems of considerable magnitude. They require

275 FLEXOR TENDON SEVERANCES
Primary Repair

	Thumb		Lesser Fingers	
DISTAL	No.	%	No.	%
Excellent	10	66	5	37
Good	3	20	5	37
Poor	2	14	4	26
PROXIMAL				
Excellent	13	62	42	41
Good	5	26	25	25
Poor	3	12	34	34
PALMAR				
Excellent	0	0	10	50
Good	1	50	4	20
Poor	1	50	6	30
CARPAL				
Excellent	2	100	20	69
Good	0	0	9	31

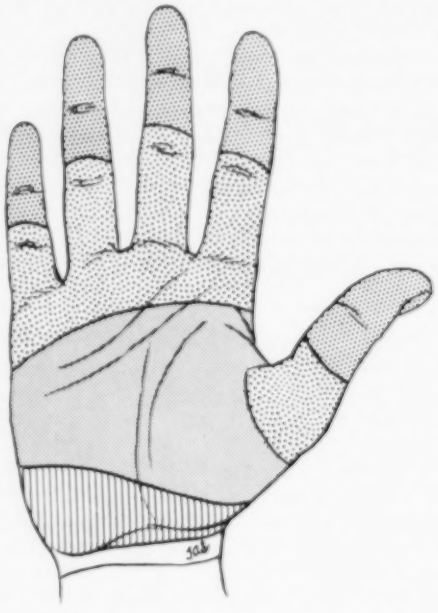

CHART III

The percentages are calculated on the basis of 252 repairs with known results. The results in twenty-three repairs are not known.

exact diagnosis, which can usually be made only by adequate surgical exposure and anatomical restoration of the damaged tendon. Fractures occurred frequently in these patients, as is common in industrial hand injuries. This adds a serious complication; reduction of fractures of the proximal phalanx should take precedence over other considerations. Injury of the extensor tendon in the distal phalanges is handled most satisfactorily by an internal splint with Kirschner wire, as suggested by Pratt. Success with external splints depends too much upon the absolute co-operation of the patient to be used routinely. A Kirschner wire in the distal interphalangeal joint of an older patient has advantages which must be weighed against the disadvantage of a small loss of extension.

In the past, results of repairs of extensor tendons have been considered good on the basis of function which many times is equal to that in an unrepaired tendon.

TABLE IV

GENERAL FEATURES OF THE OVER-ALL OPEN AND CLOSED FLEXOR GROUP (382 SEVERANCES)

	Per cent		Per cent		Per cent
White	81	Right	71	Sharp	77
Negro	19	Left	29	Crushing	23
Male	91	Clean	72		
Female	9	Dirty	28		

Level of Injury		Digit Involved		Age by Decade	
	Per cent		Per cent		Per cent
Carpal tunnel	9	1	13	1	12
Palm	7	2	29	2	5
Proximal phalanx	76	3	21	3	23
Distal phalanx	8	4	19	4	22
		5	18	5	21
				6	11
				7	5
				8	1

Flexor

The general characteristics of flexor-tendon injuries are given in Table IV. There is a definite tendency for the dominant hand to be injured; however, injuries to the left hand are more common than would be expected from the incidence of left handedness in the general population. The number of females with these injuries is low, but the incidence in females is much higher than might be expected on the basis of the relative number of women employed by the industries from which most of these patients come.

The results in the flexor-tendon injuries are categorized in order to determine what factors appear consistently in the various groups. The functional results after flexor-tendon repair, in contrast to those after extensor-tendon repair are often much less satisfactory than might be indicated by their arbitrary designation. The results of flexor repairs of the thumb are usually more satisfactory than those of the other digits. These repairs will be mentioned separately for comparison with the percentages given for the fingers in Chart III.

These operations were performed almost invariably under regional block or general anaesthesia in contrast to those on the extensor-tendon injuries. Generally, 0000 multifilament stainless-steel wire was used in the repairs, as previously described for extensor tendons. Fluffed gauze and an elastic compression bandage were used as the initial dressing, incorporating a plaster splint. The wrist and all digital joints were splinted in moderate flexion with plaster extending from the elbow to beyond the finger tips. The splint was removed to allow passive exercises twice a day after the third week and entirely after the fourth, when active motion was begun. Formal physical therapy was utilized almost entirely for about three months, but the patient's participation in obtaining a good result was constantly stressed. This is accomplished with little loss of time from work for most patients since the corporations from which the majority of these patients came maintained excellent physical-therapy facilities.

Carpal Tunnel

The patients in this group had severed tendons in the carpal tunnel. There was a greater number of injuries to the right hand than in the over-all flexor group. There were no female patients.

Surgical treatment is that outlined for the over-all flexor group with the addition of complete unroofing of the carpal tunnel. The sublimis tendons are

not repaired; they are excised as far proximally and distally as feasible through the original wound. The results are as indicated in Chart III.

At this level there were two repairs of the flexor pollicis longus; both had excellent results. There is no group of poor results for comparison. There were no significant differences between the group with good results and that with excellent results except for the incidence of permanent nerve injury. The status of the nerve was not mentioned in four cases. In the remaining cases, persistent nerve injury was noted in two of nine cases with good results and in seven of twenty-two cases with excellent results. The influence of the nerve injury on the final result is difficult to evaluate here, for, although the total result in the hand with a nerve injury is definitely poorer, the actual measurable tendon function may not be materially affected. Seven patients with excellent results had infections; all had been receiving antibiotics prophylactically. No secondary procedure was considered advisable in this group.

The results were undetermined in seven patients because six had been lost to follow-up and one died from unrelated causes before adequate follow-up time had elapsed.

Palm

There is no significant difference in this group of patients from those in the over-all flexor group except for the absence of female patients.

The technique of surgical repair was the same as that in the over-all flexor group. The sublimis tendons at this level were excised as far proximally and distally as feasible through the operative wound; however, accessory incisions are not made to excise the remnant completely. The annular ligament, if necessary, is excised completely from the area of excursion of repair (Chart III).

There were two repairs in the thumb at this level; the result was good in one and poor in the other. The poor result occurred in a patient having one of the two closed flexor ruptures in this series. Rupture followed a hammer blow to the palm in a patient with Parkinson's disease and uncontrolled tremor; the repair was believed to have pulled apart on the seventh postoperative day.

Comparison of the patients in the group with excellent and good results with those with poor results reveals some marked differences in several respects, yet enough similarity in other factors to lend significance to these differences. Considering the type of initial injury, there were no injuries categorized as crush or dirty in patients with excellent and good results. Crush injuries accounted for 75 per cent of the group with poor results, and fractures of the metacarpal accounted for 50 per cent. There were no infections in either group. All of the patients who had silk sutures had poor results. There was a disparity in age groupings; 55 per cent of the patients with excellent and good results were in the first decade, and all those with poor results were in the fourth and fifth decades. There were no patients in the second or third decade in the determinate group. The delay in treatment, averaging four hours, was twice as long in patients with the poor results. Length and type of immobilization were similar in both groups except for two repairs with excellent results in which mobilization was allowed in the first forty-eight hours as suggested by Pulvertaft[9]. Surgeons with less extensive experience operated on two patients in this group; both had good results.

There were six secondary operations; four tenolyses, giving minimal improvement, and two tendon grafts giving good results. In the group of patients with undetermined results, owing to impossibility of follow-up, there were two tendon repairs.

There were eleven tendons not repaired because of massive crushing and contamination. These were treated by tendon-grafting at a later date; the results were: eight, poor; one, good; and two, excellent. The results here were influenced by factors often following massive crushing injury: extensive fibrosis, trophic disturbances, and incomplete restoration of normal skeletal anatomy.

Proximal

The incidence of injury to the left hand was almost double that of the over-all flexor group and over four times the incidence of left-handedness in the general population. There were twice as many females in this group as there were in the over-all flexor group (Table IV).

The technique of tendon repair at this level was the same as that used in the over-all flexor group; however, excision of the sublimis tendon at the level of the proximal interphalangeal joint was also performed. Care must be taken to ensure the complete separation of the two sublimis slips so that the process of withdrawing the tendon into the palm does not tear the vincula and also withdraw the profundus. The distal stumps of the sublimis slips are attached to the proximal edge of the joint capsule to prevent their adherence at a more proximal level while the finger is splinted in flexion. The annular ligament is excised from the expected area of excursion of the repaired portion of the tendon. This usually requires sacrifice of one of the pulley areas, sometimes two. If feasible, one of the sublimis slips is utilized to reconstruct a new pulley at the site where it will not come in contact with the sutured part of the tendon. Free tendon or fascia to re-create a pulley at this stage is not used (Chart III).

There is a discrepancy between the number of tendons severed and the number actually repaired in the proximal group due to the fact that some of the lacerated sublimis tendons were not repaired. The partially lacerated and damaged sublimis tendons surgically excised are not included in the calculations. There were 171 tendons severed with 134 tendon repairs.

There were twenty-one repairs in the thumb, the results of which were excellent in 62 per cent; good in 26 per cent; and poor in 12 per cent. These results were considerably better than those in the other digits.

Comparison of the group with excellent and good results with the group with poor results reveals a number of differences. Females constituted 3 per cent of the group with excellent and good results and 20 per cent of the group with poor results. Technical errors were committed in 20 per cent of the group with poor results and 2 per cent of the group with excellent and good results. Crushing injuries were approximately equal. Fractures and infections were twice as common in the group with poor results, and dubious vascularity was three times as common. Skin loss and division of a digital nerve were equally divided among the groups. Wounds described as dirty were found in a higher percentage of patients with excellent and good results.

The duration of immobilization was three weeks in the vast majority. There were nineteen repairs followed by early motion (forty-eight hours), with excellent results in eighteen and poor results in one. This limited number of cases represents a highly selected group in which the technical performance, the intelligence of the patient, and the initial injury were all favorable to an excellent outcome. I do not feel that conclusions should be drawn unless such a method is applied to a larger unselected group.

The results with various suture material show slight differences in the various groups. In the group with excellent and good results, 75 per cent of repairs by 0000 wire were in the group with good and excellent results; 65 per cent of repairs by tantalum barbed wire, and 53 per cent of repairs by silk suture also were in the group with excellent and good results. Each of the surgeons had approximately the same experience in each group.

Secondary operations—neurolysis, scar revision, and a cross-finger flap—were performed in three repairs with excellent results. The cross-finger flap, from the adjacent index finger, was needed for an area of dry gangrene developing in the soft tissue over the area of the tendon repair in the thumb. An area of skin and fat was excised, approximately one centimeter in diameter, on the fifth post-operative day without placing undue tension on the tendon repair. In the group with good results, there were four tenolyses with improvement that was not suffi-

cient to change the category and one pulley reconstruction that changed the classification to excellent. There were thirteen secondary operations in patients with poor results: three tendon transfers, in two of which the results remained poor and in one of which the result became good; six tendon grafts, four with good and two with unknown results; and four amputations.

An anomaly—fusion of the sublimis and profundus—was noted during two repairs at this level. The profundus appeared to be only an extension of the sublimis and had no independent action. The situation cannot be clarified since the palm and forearm were not explored. The possibility of an unremembered injury or infection in early life causing fusion of the two tendons cannot be ruled out.

107 FLEXOR TENDON SEVERANCES
Delayed Repair

	Thumb		Lesser Fingers	
PROXIMAL	No.	%	No.	%
Excellent	1	25	19	29
Good	2	50	14	21
Poor	1	25	33	50

CHART IV

The percentages are calculated on seventy repairs with known results. The result in one repair is not known.

Distal

This group shows little variation from the over-all group. There are slightly more female patients and a slightly higher ratio of middle-aged patients. There was a distinct tendency to cut several digits simultaneously.

Two surgical techniques have been employed in an approximately equal number: repair of the tendons within the finger and advancement, and fixation of the proximal portion of the tendon to the distal phalanx. The distal stump, if less than .75 centimeter in length or if frayed, is excised, and a raw area created on the distal phalanx. A drill hole is made through the distal phalanx to the nail. The end of the tendon is held with a 0000 wire mattress suture passed through the drill hole and secured over a button on the dorsum. If the distal stump is longer, it is split, and the proximal tendon stump is sutured into the split. Sufficient

tendon is excised to ensure that the repair is advanced clear of the sublimis slips. The proximal tendon stump is held by a mattress suture of 0000 wire to a button on the finger tip. The wire is withdrawn at the end of three weeks.

The one closed injury in this group was a tear of the profundus at its insertion, which occurred while the patient was dribbling a basketball. The result after reinsertion of the tendon into the distal phalanx was excellent. This patient had an anomalous flexor tendon similar to that described in the two previous cases (Chart III).

Lacerations of the distal portion of the flexor pollicis longus account for fifteen of the thirty-one repairs of this tendon. The results in ten of these thumb repairs were excellent.

It should be mentioned that the result of an unrepaired distal laceration of the flexor can be good and that joint tenodesis or arthrodesis in a satisfactory position will allow the finger tip to approach within half an inch of the distal palmar crease. It is obvious that repair of the tendon offers active control of the distal joint. Repair should be undertaken in a patient who needs the active motion and not in one for whom the stability offered by tenodesis or arthrodesis would be sufficient.

Comparison of the group with excellent and good results with the group with poor results shows some areas of similarity. The surgeons were experienced in all cases. There were no infections. Antibiotics were administered prophylactically to all patients.

In the group with poor results there was dubious vascularity in 64 per cent of the cases, crushing injury in 100 per cent, and fractures in 32 per cent. In the group with excellent and good results there were no cases with dubious vascularity, and there were crushing injuries in 15 per cent and fractures in 8 per cent.

Loss of skin requiring rotation or other flaps and skin grafts was twice as common in the group with poor results.

Secondary procedures were done on all the patients with poor results. These included four amputations and two arthrodeses of the distal interphalangeal joint.

Four of the repairs required amputations for gangrene. In spite of the relative ease of repairing tendons at this level, the primary procedure in these fingers should have been limited to a skin closure. The additional trauma of repairing a tendon can be a deciding factor in the loss of a finger tip. A delayed advancement could be done after viability of the finger had been assured.

DELAYED SURGERY

Proximal Phalanx

The patients in this category represent those seen as part of the initial group. It does not include patients with healed wounds referred for secondary tendon repairs or grafting. In many instances these patients had massive hand injuries in which tendon-grafting was carried out to give a slight increase in usefulness to an otherwise crippled hand. This group is included to account completely for all patients seen and not to compare the virtues of secondary repair over primary repair.

The primary procedure in this group was skin closure and in some instances neurorrhaphy. In isolated instances it was necessary to utilize grafts or flaps to obtain closure. The initial tendon repair was deferred for various reasons considered inimical to good surgical results. It is only the repairs in the proximal phalanx which involve particular problems since in other areas essentially the same procedure can be carried out after delay as would have been done at the primary operation. There is a discrepancy here between the number of repairs and the number of severances studied at this level similar to that noted in the group with primary repair of the tendon in the proximal phalanx. There are 107 severances with seventy-one repairs (Chart IV).

TABLE V

REASONS FOR DELAYING REPAIR IN 107 SEVERANCES OF THE FLEXOR TENDON WITHIN THE AREA OF THE ANNULAR LIGAMENT*

Dubious vascularity of digit	16
Fractures	15
Crushing of soft tissue	21
Meddlesome first-aid	7
General condition of patient	1
Patient did not desire treatment	3
Misdiagnosis by our service	4
Misdiagnosis elsewhere	17
Skin loss requiring a graft or flap	6
Contamination	21
Excessive delay	14
Digital nerves severed	18

* Repair delayed for more than one reason in some cases.

TABLE VI

REASONS FOR SECONDARY REPAIRS NOT BEING DONE IN THIRTEEN CASES

Patient motivation insufficient	2
Insensate finger after neurorrhaphy	2
Vascular insufficiency	3
Residual disability minimal	2
Poor joints and cicatrix	2
Patient refused surgery as such	2

There were four secondary repairs in the group with good and excellent results and none in the group with poor results. The magnitude of original injury in the patients with poor results accounts for this rather than any superiority of the secondary tenorrhaphy over the tendon graft.

Thumb injuries accounted for four delayed operations, with one excellent result, two good results, and one poor result.

Failure to do a primary tendon repair because of misdiagnosis elsewhere accounted for twenty-four delays and misdiagnosis by our service accounted for four delays. The remaining seventy-nine procedures were delayed by surgical judgment for the reasons given in Table V.

The majority of the reasons given for the failure to do a primary tenorrhaphy were also present in the group with repair but, as the figures indicate, there was a multiplicity of unfavorable factors in the group without repair.

A small group of patients was denied, or refused to have, secondary repair because of various reasons, which are listed in Table VI.

The listing of lack of motivation or understanding on the part of the patient as the first reason for the denying of secondary repair is not due to chance. A prime advantage of delayed repair is the opportunity to learn which patients are going to work for a good result, and the surgeon should not deprive himself of such an opportunity. Five patients of this group were advised to have amputation when first seen, but refused until the wisdom of this advice slowly became apparent. The insensate finger after neurorrhaphy is an absolute contraindication to tendon repair. The finger with vascular insufficiency is also considered a poor choice for repair, and experience here with this type of finger has been dismal. A patient has seldom been denied surgery because of poor joint motion or scar, even though it is felt that the results will be poor. This limited range contributes to the over-all strength of the hand and is very useful in hands of which several fingers have been injured. In the single-finger injury, however, amputation, tenodesis, or arthrodesis of the finger joints should be considered when a satisfactory range of passive motion cannot be established.

The tendon grafts were palmaris longus when feasible; toe extensors and sublimis grafts were also utilized but not frequently enough to compare them with the palmaris group.

The surgical handling of the tendons in this group was relatively constant. The profundus tendon and sublimis tendons were excised. A tendon graft was inserted from the level of the lumbricales to the distal phalanx. The sublimis of an adjacent digit was used as a motor only in long-standing disuse of the profundus. In two cases of severance of the flexor pollicis longus where the original motor was considered unsuitable, transfer of a sublimis tendon was performed rather than a graft.

The tendon graft was inserted at the distal phalanx into an area of freshened bone or beneath a small osteoperiosteal flap. The grafts were fixed with a mattress or figure-of-eight stitch of multifilament 0000 stainless-steel wire through a drill hole in the bone to a button on the dorsum.

The proximal portion of the graft, as mentioned, is attached to the profundus at the level of the distal lumbricalis muscle belly which is utilized to cover the suture line. The proximal attachment is made with a fish-mouth incision into the profundus for sublimis or larger size palmaris longus grafts, and a double buttonhole type of insertion for the extensor and smaller caliber palmaris grafts. The proximal attachment was made with silk in the earlier cases, but multifilament 0000 stainless-steel wire is now used.

The annular ligaments are excised throughout their length, leaving pulleys at the head of the metacarpal, head of the proximal phalanx, and at the mid-point of the mid-phalanx.

The tendon grafts are immobilized for three weeks by means of a splint, with the wrist and all finger joints flexed. The splint is worn for an additional week except during twice-daily periods of soaks and passive exercise. The adhesions, if any, are broken at the end of the fourth week by carefully manipulating the digit through its full range of motion with the wrist flexed. The patient should be relaxed and his full co-operation assured by a full explanation of what is to be done. The splint is discarded, and the patient is encouraged to do manual labor of any and all types from this time on.

The magnitude of the original injury is indicated by the high incidence of complicating injuries which amounted to twenty-seven in the group with excellent and good results and eighty in the group with poor results. Phalangeal fractures were eight times as common in the group with poor results as in the group with excellent and good results. All the work of the less experienced surgeons was on the group with poor results. Silk was used twice as frequently in the group with poor results.

There were twelve female patients in the group with poor results and none in the group with good and excellent results. This figure is one which I am at a loss to explain, inasmuch as the female patient as a rule has a lesser injury and co-operates more completely in her treatment.

The Negro patient appears more than twice as frequently in the group with poor results, perhaps because the tendency of his race to form excessive scar tissue jeopardizes the result in this critical area.

The age of the patient has some bearing inasmuch as the group with good and excellent results is significantly larger in the third and fourth decades and the group with poor results is larger in the fifth and sixth decades.

Unwanted motion of the tendon occurred four times in the group with poor results in the first and second weeks because of broken splints or removal of the splints by the patient but did not occur in patients in the group with excellent and good results. I am not suggesting that early motion is detrimental to a tendon graft but only that unsupervised early motion may well be disastrous.

Secondary operations have not been very successful in our hands in the group with tendon-grafting. Two tenolyses were carried out in the group who had

excellent results, with some subjective relief of tight sensation in the palm but no change in the range of motion. Two tenolyses were done in the group who had good results, with improvement to excellent. Two tendon-shortenings improved flexion but at the expense of extension. There were sixteen secondary procedures in the group who had poor results which included three amputations, six tenolyses, five scar revisions, and two rotation flaps. Excluding amputations, all resulted in improvement, but not to the extent of advancing these patients to the category of excellent and good results.

CONCLUSIONS

Injuries of the flexor tendons should be repaired primarily in the carpal tunnel and at the palmar level when the character of the wound permits. Muscle shortening is greater at this level and may prevent sufficient amplitude of motion for successful late tenorrhaphies or grafting procedures. The results in the palmar group of this series are distinctly disappointing. The temptation to repair the tendon in a severe hand injury is great, partly because of the desire to return the patient to gainful employment as rapidly as possible, and partly perhaps because the realization of the difficulties that will be encountered when reentering a severely scarred hand may influence the surgeon's desire to complete the job primarily. The long experience of Koch, Mason, and Allen in dealing with this type of injury should be paid greater heed. We have repaired tendons in the presence of compound fractures with intramedullary Kirschner-wire fixation, feeling that the firm fracture fixation would allow handling of the problem associated with the tendon as if there were no fracture. The results indicate that this is a fatuous assumption.

As for the flexor tendon cut within the area of the annular ligament, a series of problems arise, as previously noted. It must be recognized that tendon function depends on the gliding surface of the sheath and the precise angles of approach of the tendon to its points of leverage furnished by the annular ligaments. The blood supply at this level is tenuous and is from the major vinculum. All of these structures may be damaged by the injury or the subsequent efforts of repair. In many instances the tendon is only slightly better than a free graft with respect to its blood supply. Such a tendon must necessarily adhere to survive. To give the repair the success rate comparable to tendon-grafting would require widespread opening of the hand and excision of the remaining sheath except for pulleys, which is hardly an advisable procedure in a contaminated wound. Repair of the thumb flexor is subject to similar obstacles but to a lesser degree. However, the results obtained, I believe, warrant continuance of primary repairs of the thumb flexor when the wound is suitable.

The results of selected and unselected primary repairs are compared graphically in Chart V with selected and unselected tendon-graft groups of roughly comparable size [1,10]. The primary groups have a larger number of cases in the fourth and fifth decade than the Pulvertaft [10] group; the ages of the patients of Boyes could not be determined from his data. The ideal primary group was selected from twenty consecutive cases which preoperative assessment led us to believe were ideal—clean incised wounds without injury to nerve or bone repaired within four hours. The results were better than the unselected primary repairs but woefully short of the "good" group of Boyes. The most discouraging aspect of the charts is that clinical judgment was so deficient in selecting the so-called ideal case in contrast to the reliability of predicting the behavior of tendon grafts from preoperative assessment.

At the onset of this study I had hoped to demonstrate that primary repairs of the flexor tendon within the digit were indeed desirable when done by hand surgeons. Unfortunately, this can only be said of the injuries distal to the area of the annular ligament. In the area of the annular ligament the surgeon faces certain anatomical limitations, as well as the vagaries of the injury that make

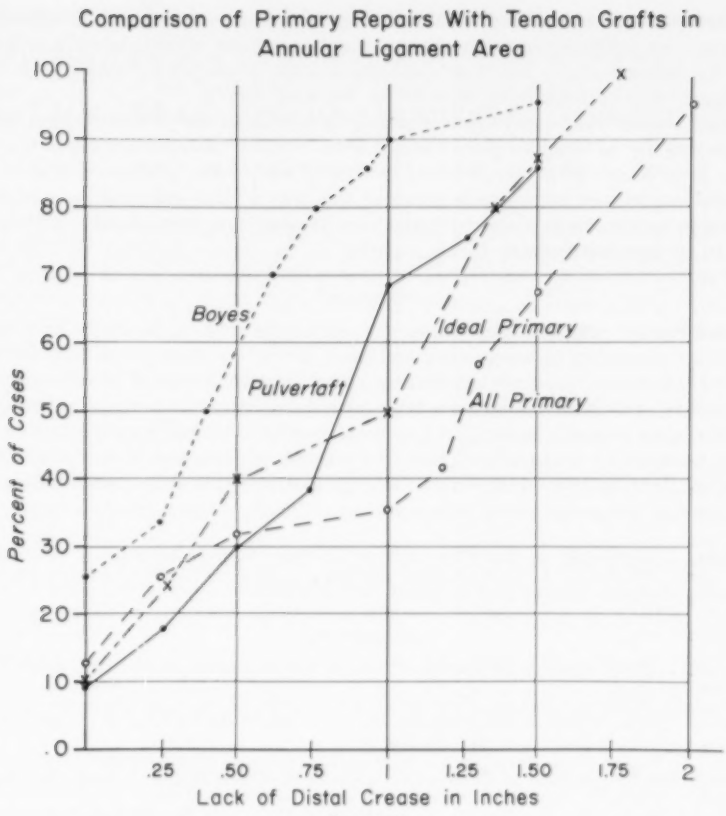

CHART V

Boyes: twenty consecutive "good" cases.
Pulvertaft: ninety traced cases with three cases deliberately excluded.
Ideal Primary: twenty consecutive "ideal" cases.
All Primary: 111 traced cases.
(No thumb repairs are included in the figures above.)

this an unwise procedure except under highly unusual circumstances. The results after primary repair by hand surgeons are materially improved, but they seldom approach those after secondary repair by tendon-grafting.

Hauge's conclusion has one further point worthy of emphasis and that is the referral to a hand-surgery service for secondary treatment. The widespread adoption of secondary tendon-grafting by surgeons not intimately familiar with the problems of hand surgery, who hope that they will have results comparable to those published by Boyes or Pulvertaft, is not realistic. It is akin to the sand-lot ballplayer who thinks that he will be able to bat like Ted Williams by eating the right brand of breakfast food.

COMPLICATIONS

The major complications of this series were the result of antibiotic administration, psychiatric disturbance, and block anaesthesia. There were two cases of anaphylactic reaction to penicillin, in patients who were questioned about drug reactions prior to the administration of penicillin. Both patients required herculean efforts to save their lives. It was felt that had either of these reactions occurred anywhere except in a well equipped emergency ward, these patients would not have survived. Both had relatively minor extensor-tendon injuries.

One patient hospitalized with an injury of a finger extensor at the proximal phalanx was extremely depressed, especially about his ability to earn a living with an injured hand. He was discharged after psychiatric consultation and clearance, and he committed suicide on the next day.

One patient had a persistent burning in the ulnar-nerve distribution which we felt was due to brachial plexus anaesthesia. Another patient developed wasting of the arm flexors of a very selected character which was attributed also to the anaesthesia, but the neurologists felt that this was a virus infection or a reaction to immunization. Both these patients were treated symptomatically, with a return to preoperative status in six months.

SUMMARY

Antibiotics, regional anaesthesia, and improved surgical facilities have made the repair of tendon injuries easier and more attractive than previously. The results of this study indicate that crushing fractures and vascular insufficiency are still problems of great magnitude. It is incumbent upon the surgeon to recognize that the therapeutic advances in the past decade have not appreciably altered tissue reaction to trauma, and that the success of primary repair depends on proper evaluation of these factors as well as upon surgical skill. I have attempted to delineate the areas where primary repair is still a worth-while venture.

NOTE: I should like to thank Dr. Marion W. Jocz, Medical Director of the Chrysler Corporation, and Dr. E. A. Irvin, Medical Director of the Ford Motor Company, and their associated physicians who assisted so greatly in this work.

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DISCUSSION

DR. JOSEPH L. POSCH, DETROIT, MICHIGAN: During this same period of time, July 1, 1952, to June 30, 1957, we had 770 patients with injured tendons at the City of Detroit Receiving Hospital. This number, with the 706 that Dr. Kelly has presented here this afternoon, makes a total of 1,476 patients. I present this merely to illustrate the great number of tendon injuries that are encountered in a large metropolitan area. In our series no attempts have been made for a follow-up study such as Dr. Kelly has so excellently presented. The majority of our patients are transients, thus follow-up is impossible.

The method of study that has been presented here today is good, and again reveals the number of variables that are encountered. I believe that one can safely say that no two injured hands are exactly alike, even if the lacertion and tendon appear to be identical in the injury. There are still, of course, the patient's individual response to the accident, and his healing power, psychological reaction, and so on to deal with. In my opinion, Dr. Kelly's criteria for evaluating his results are too critical. I am sure that most of these patients have improved function and can return to their jobs with good, usable hands.

It was interesting to see the number of mallet-finger injuries treated by Pratt's method and the good results obtained. We have used this method only on two occasions, relying more on external splinting or a Kirschner wire through the d stal joint. In extensor-tendon injuries

(Continued on page 664)

Anatomical Considerations in the Primary Treatment of Tendon Injuries of the Hand*

BY CARL L. HOLM, M.D., AND RICHARD P. EMBICK, M.D., SALEM, OREGON

Acute hand injuries confront the surgeon with many difficult decisions. The divergence of opinion, which seems to persist in regard to certain phases of hand surgery, only attests to the complexities and unsolved problems of restoring function to the injured hand. As a study of anatomy is basic and essential to the understanding of hand surgery, an attempt has been made to correlate the intricate functional anatomy of the hand with the present-day concepts of primary treatment. A review of the literature and the response to a questionnaire submitted to a number of authorities and hand centers throughout the world also served to provide valuable information and background for this presentation. A detailed analysis of the questionnaire will be submitted in a subsequent paper.

Modern transportation and readily accessible, specialized surgical facilities make it possible to carry out early and more definitive treatment of hand injuries well within the time limits of sound surgical principles of wound care. The problems of hand surgery today are mainly those of anatomical diagnosis, surgical judgment, and surgical technique. Well planned and orderly primary surgical treatment provides the best chance for ultimate restoration of function to the injured hand.

Tendon injuries have received special consideration in this study. The conclusions presented represent the conservative approach and are most applicable to those surgeons who do not consider hand surgery to be their major specialty.

The intricate anatomy of the many structures involved in hand injuries more than anything else dictates the order of repair. Table I illustrates the priority which the various hand tissues command in primary treatment. Viable tissue, skin coverage, a well aligned mobile skeletal framework, and sensory and motor function are all prerequisites to successful restoration of tendon function. Circulatory damage and skin loss must necessarily receive first consideration in treatment. Resection of devitalized tissue, conversion to a surgically clean wound, and skin replacement, where deficits exist, are necessary for primary wound healing. Next, the skeletal system must be restored and functional alignment maintained. Severed hand and digital nerves are best repaired immediately. The more resistant nerve tissue better tolerates primary repair. Therefore, good results can be achieved and are essential in preparing the hand for subsequent reconstructive procedures.

A basic knowledge of histology and physiology of tendon tissue is important in the treatment of tendon injuries. Tendons are composed of specialized, dense, white connective tissue with parallel, inelastic, adherent fibrils and sparsely interspersed cells and vessels. They are provided with a longitudinal network of intratendinous and paratendinous nerves arising from muscle as well as from regional nerves. The paratendinous fibers are known to communicate with digital nerves. Pain sensation from tendons is believed to arise from free endings and nerve fibers. Proprioceptive endings include Ruffini spindles and encapsulated corpuscles of Pacini and Golgi [49]. Although the metabolism of tendon tissue is low, tendons are not inert structures. They respond to physiological stress by hypertrophy. Disuse results in degeneration. When lacerated, tendon ends become oedematous and proliferate. They adhere to paratenon and other injured tissue

* Read in part at the Annual Meeting of the North Pacific Orthopaedic Society at Eugene, Oregon, May 10, 1957.

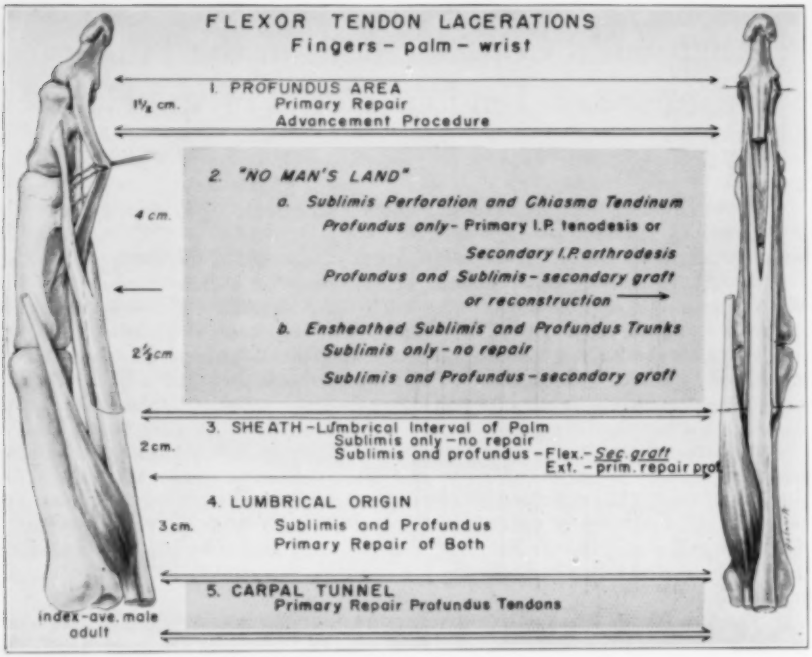

CHART I

in Nature's attempt to restore continuity. The tendency for tendons to proliferate makes it essential that these ends be carefully coapted, leaving no unopposed fibers. It also follows that the site of repair should be kept well away from the wound, if possible. Bunnell [11] and others have observed that when an ensheathed severed tendon retracts, the retracted end does not proliferate or become densely adherent within the sheath.

The hand has some thirty-eight muscles and tendons with flexor, extensor, and intrinsic muscles existing in a delicate state of balance which must be preserved and coordinated with an opposing, independent thumb.

Charts I, II, III, and IV * attempt to demonstrate the surgical anatomy of the flexor and extensor apparatus of the fingers and thumb at various levels, depicting the appropriate surgical treatment. Stippled sections represent critical areas of repair with the italicized print indicating secondary operative procedures.

FLEXOR-TENDON INJURIES

Flexor-tendon injuries will be considered first. A few general remarks in regard to the anatomy of the flexor tendons are in order. These round, strong tendons are deeply situated in the palm and fingers. In the fingers they are enclosed in an inelastic, fibro-osseous tunnel with thin cruciate fibers over the joints and thick transverse fibers over the phalanges. The thickened phalangeal sections of the fibrous sheaths form the pulleys or annular ligaments. The synovial sheath is an intimate part of the fibrous sheath and contains parietal and visceral layers with synovial bands or vinculae which are vestiges of the mesotendon found in

* The drawings by Clarice Ashworth are based upon anatomical dissections at the Surgical Anatomy Laboratory of the University of Oregon Medical School and upon experimental lacerations on fresh specimens.

the palm. The fibro-osseous tunnel is closely associated with a thick, cartilaginous palmar plate or ligament called the accessory volar ligament which reinforces the joint capsule of the interphalangeal and metacarpophalangeal joints. Flexor-tendon blood supply is poorest in no man's land since it is derived chiefly from the vinculae and synovial reflections. Very few vessels reach the tendons through the osseotendinous junction. In the palm, the mesotendon and musculotendinous junction provides additional vascularity. According to Kaplan [23], functional excursion of the flexor tendons over the metacarpophalangeal joints in the palm ranges from 2.75 centimeters to four centimeters for the profundi and from 2.25 centimeters to 3.5 centimeters for the sublimi. Tendon excursion is greatest in the ring finger.

Chart I illustrates the flexor apparatus of a finger and its relationship to the underlying bones and joints, dissected and drawn to scale from an index finger of an adult of average size. It has been divided into six basic anatomical areas of injury and repair:

TABLE I

TISSUE PRIORITIES AND GOALS IN THE PRIMARY TREATMENT OF HAND INJURIES

1. Circulatory	
	Preserve volar arches and superficial venous plexuses
	Prevent oedema and fibrosis
2. Dermal	
	Resect devitalized skin
	Primary skin coverage and closure
3. Skeletal	
	Restore alignment and arches
	Preserve joint mobility
4. Neuromuscular	
	Restore sensory and motor function
	Prevent contracture and trophic changes
5. Tendon	
	Restore transmission cables
	Reconstruct gliding mechanisms

1. *The distal profundus area:* This area extends from the insertion of the profundus on the distal phalanx to the insertion of the sublimis midway on the shaft of the middle phalanx. Lacerations in this area involve only the profundus tendon, making primary repair possible. Excessive retraction is prevented by the vinculae. The proximal tendon end can be advanced and sutured directly to the distal phalanx. The junction should be placed well distal to the interphalangeal joint, avoiding adhesions in the region of the joint and volar plate to ensure independent flexion of the distal phalanx. Advancement is limited to approximately one or 1.5 centimeters if a flexion contracture is to be avoided. Because of the mesotendon and interdigitation of the profundi in the proximal palm and because of the lumbrical origin, profundus-lengthening procedures in the wrist are not practical.

2. *No man's land:* This critical and complex region reaches from the insertion of the sublimis on the middle phalanx proximally to the termination of the flexor sheath in the palm. Anatomically and surgically it can be divided into two parts:

A. *The area of sublimis division and chiasma tendinum of Camper* extends from the center of the middle phalanx to the middle of the proximal phalanx. With the finger fully flexed, the sublimis division moves to the proximal finger crease.

The anatomy of the sublimis division and its relation to the profundus were described in minute detail as early as 1734 by Bernard Albinus, a German anatomist, who divided it into six parts. Later, a Dutch physician and anatomist, Peter Camper, described this area and affixed the name *chiasma tendinum* to the decussation of the sublimis. Kaplan, in his excellent book on the anatomy of the hand,

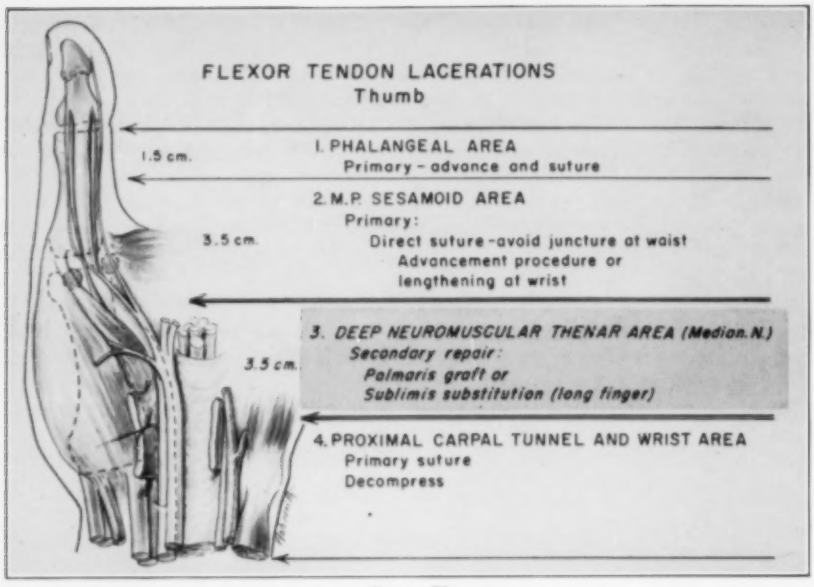

CHART II

describes the work of these two men and states: "The division of the sublimis tendon into these component parts is seldom described and may be of importance in helping to overcome failures of tendon surgery in the region of the finger so aptly called 'no man's land' " [23].

The profundus tendon in this region lies superficially and may be lacerated without involving the entire underlying sublimis decussation as far as the proximal finger crease with the finger in flexion. In such instances it is sound practice to leave the profundus unrepaired, preserving sublimis function by encouraging early motion. In regard to lacerations in this area, Rank and Wakefield make the following comment: "It is a good rule in primary treatment that the function of an intact sublimis tendon should never be sacrificed or jeopardized" [44]. Kyle and Eyre-Brook feel that the result of leaving a profundus laceration unrepaired in the presence of an intact functioning sublimis falls little short of a secondary profundus graft. As a primary procedure, one can elect to do a distal interphalangeal joint tenodesis which will not jeopardize the sublimis, and then close the wound. A secondary interphalangeal joint arthrodesis can be done at a later date, should it be necessary. It is the exceptional case, even when the index finger is involved, which justifies the secondary use of a thin palmaris or plantaris-tendon graft to restore profundus action in the presence of an intact functioning sublimis.

When both the profundus and sublimis are cut in this area, it is best to close the wound primarily and carry out a secondary reconstructive procedure at a later date. Retraction is variable depending upon the degree of involvement of the vinculae and chiasma. The intricate anatomy in this region, together with the tendency for tendons to proliferate and adhere to surrounding structures when cut, all but defies any form of successful primary tendon repair except, perhaps, by the expert. If primary repair is attempted, the profundus only should be sutured after resection of the sublimis.

B. *The ensheathed sublimis and profundus trunks* extend from the proximal sublimis division to the termination of the sheath in the palm. Here the sublimis lies superficially and may be the only tendon lacerated. If so, the sublimis laceration should be disregarded as early motion will maintain profundus ex-

cursion and ensure a functioning finger. When both the sublimis and profundus are severed in this area, retraction may be excessive and a secondary tendon graft becomes the procedure of choice.

3. *The sheath-lumbrical interval of the palm:* This portion of the flexor tendons in the mid-palmar region extends between the proximal end of the fibrous sheath and the lumbrical tendon. Superficial lacerations may involve only the sublimis. This lesion may not be recognized because of little functional loss in the finger. The sublimis need not be repaired. When both tendons are lacerated in this area, the manner of repair is influenced by the position of the fingers at the time of injury. Experimental lacerations were made on unembalmed hands at the level of the distal flexor crease in the palm. In the fresh specimen, lacerations were found to extend through the termination of the fibrous sheaths dividing the sublimi and profundi and to pass through the thick palmar plate into the metacarpophalangeal joints. When lacerated with the fingers in full extension, the distal ends of the sublimi and profundi naturally remained at the line of incision. The proximal ends of the profundi retracted to the level of the lumbrical origins, while the sublimi moved a little beyond these origins. Flexion of the fingers to a position of rest or to a position suitable for repair moved the distal end proximally out of the sheath and into the sheath-lumbrical interval, a distance of approximately one to 1.5 centimeters. In lacerations made with the fingers in maximum flexion, again at the distal flexor crease of the palm, the proximal tendon ends remained in close proximity to the line of incision. Upon extension of the fingers, the distal ends moved into the fibrous sheath of the finger, a distance of 1.5 to two centimeters depending on the finger. Therefore, in lacerations of the hand made through the distal palmar crease with the hand in extension, primary repair is possible as the juncture will lie in the sheath-lumbrical interval of the palm with the fingers flexed to the position of rest. In such an instance, suturing only the profundus is advisable, as no barrier to cross union with the sublimis exists at this level. Excision of the palmar portion of the fibrous sheath gives additional room for repair. On the other hand, if the tendons are lacerated in flexion, the wound only should be repaired and a secondary graft carried out at a later date for the junction of the tendon ends with the finger in a position suitable for repair would lie within the flexor sheath distal to the metacarpophalangeal joint.

4. *The area of lumbrical origin on the profundus:* When the superficial and deep flexor tendons are lacerated in this region, primary repair of both tendons is feasible since the lumbrical muscle can be interposed between them to prevent cross union. The lumbrical should be interposed with minimal suturing to avoid damage to its nerve supply and to avoid limiting its action. The nerves to the first two lumbrical muscles enter volarly from the digital branches of the median nerve and the nerves to the third and fourth lumbricals enter dorsally from the deep motor branch of the ulnar nerve. Contracture of the lumbrical would limit excursion of the profundus. Extensive lacerations with involvement of multiple tendons and nerves may necessitate sacrificing the sublimi and concentrating on repair of the more important profundi and palmar nerves.

5. *Carpal tunnel:* A laceration extending entirely through the carpal tunnel would sever nine tendons and the median nerve, a situation which makes repair very difficult. However, because of excessive retraction at this level, attempts should be made to repair the profundi and flexor pollicis longus primarily. Also, the median nerve should be repaired initially. The ulnar bursa, which envelops the profundi from the ulnar side, should be resected or wrapped about the tendon junctures in an attempt to prevent adherence. Decompression can be accomplished by making the incision in the transverse carpal ligament along its medial or lateral attachment and leaving it unsutured. If possible, the junction of the tendon ends should not be placed within the carpal tunnel. This can be avoided by positioning of the wrist.

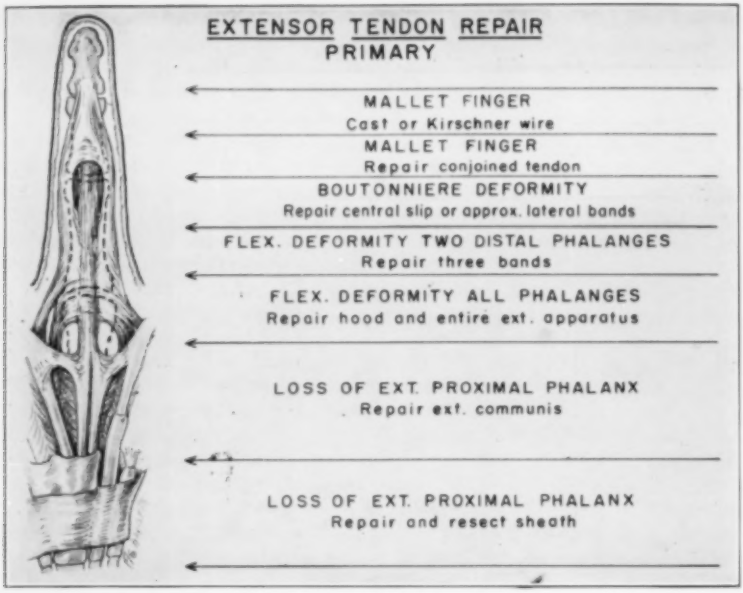

CHART III

6. *Wrist:* Primary repair in the wrist is essential and anatomically more practical because the synovial sheaths or bursae terminate in the wrist and blend with the vascular paratenon. Also, the rich blood supply from the musculotendinous junction facilitates primary repair.

Chart II demonstrates the anatomy of the long flexor tendon of the thumb, drawn to scale, designating the appropriate repair of lacerations at various levels. The flexor pollicis longus tendon ordinarily has no vinculae, and is without a lumbrical muscle. This tendon lies in the carpal tunnel within its own sheath, radial to the profundi, and its muscle is usually independent of the finger flexors. The digital sheath of the flexor pollicis longus has a fibrous component which extends to the metacarpophalangeal articulation, forming a pulley over the proximal phalanx. The sheath is constricted as it passes the sesamoids and only the synovial layers extend into the palm and wrist. The anatomy of the long thumb flexor facilitates tendon-lengthening during primary repair of lacerations, because a wrist incision is almost always required in order to find the retracted proximal segment.

The flexor pollicis longus can be divided into the following areas of injury and repair: (1) phalangeal area, (2) metacarpophalangeal sesamoid area, (3) deep thenar area, and (4) proximal carpal tunnel and wrist area.

Distally, the phalangeal portion of the tendon can be repaired primarily as in the fingers by the advancement procedure.

Direct suture with resection of the sheath is possible in the metacarpophalangeal area of the flexor pollicis longus, but juncture in the constricted sesamoid portion of the sheath or wrist should be avoided. This can be accomplished either by advancement after resecting a segment of tendon or by advancement following tendon-lengthening at the wrist.

In the thenar area, the tendon lies deep in the palm beneath important neuromuscular structures. Primary tendon repair is possible in the deep thenar area, but because of the more important overlying digital and motor branches of the median nerve, surgical approach in this area must be considered in light of the

location and extent of the wound. If the initial trauma also severed the nerve, then both the tendon and nerve should be repaired providing no other contra-indications exist. If a penetrating wound has left the nerve intact, secondary repair by grafting or substitution would seem to be preferable. A sublimis substitution or transfer procedure is practicable secondarily, as length of the long or ring finger sublimis is sufficient to reach the base of the distal phalanx of the thumb. This procedure is also applicable for tendon replacement in the little finger.

In the proximal carpal tunnel and in the wrist, the thumb flexor tendon is well situated anatomically for primary repair. The sheath at the site of repair must be resected, and the laterally incised retinaculum should again be left unsutured.

The long thumb flexor acts primarily on the distal phalanx. Therefore, if the long flexor cannot be repaired arthrodesis of the interphalangeal joint in flexion will restore a useful thumb, if the thenar motors have not been previously damaged.

EXTENSOR-TENDON INJURIES

All of the extensor tendons can usually be repaired primarily, if the skin coverage is adequate. In contrast to flexor tendons, delayed primary repair is frequently possible. This procedure is often valuable in treating neglected or undiagnosed tendon injuries. Associated fractures do not necessarily contra-indicate primary suture. Extensor tendons are provided with paratenon, a specialized, loose, fatty, elastic connective tissue which ensures a better blood supply for healing and acts as a gliding mechanism. In contrast to flexors, the excursion of the extensor tendons is shorter and their motors are weaker, placing less stress at the site of suture. On the other hand, certain anatomical features call for great care and exacting technique in repair or replacement. Extensor tendons are extremely thin, form a part of the joint capsule, and lie in close proximity to bone and skin. The complex relationship existing between extensor tendons and the intrinsic mechanism must be preserved.

Chart III illustrates the anatomy of the extensor apparatus of a finger and the corresponding deformity from injuries at the various levels.

The common mallet-finger deformity may be due either to laceration or avulsion of the conjoined tendon with or without a bone fragment. Primary repair is indicated in lacerations of the tendon. The more common avulsion injury is best treated conservatively by a finger cast, maintaining only the distal interphalangeal joint in extension. Recently, the use of a Kirschner wire without external fixation has been advocated [38]. Should postreduction films reveal an unreduced fragment, open reduction may be required. Often these injuries, accompanied by varying degrees of flexion deformity, are seen too late for conservative treatment. Operative repair is indicated only if spontaneous healing has not resulted in a stable joint and a useful range of extension. Mild residual deformity is not an indication for surgery. Severe untreated mallet-finger deformity may lead to hyperextension of the proximal interphalangeal joint because of unbalanced pull of the central slip.

Lacerations in the region of the proximal interphalangeal joint may involve the central extensor slip to the middle phalanx. This causes a buttonhole deformity which may not be immediately recognizable. The deformity consists of flexion of the proximal interphalangeal joint and extension of the distal interphalangeal joint because of volar displacement of the lateral bands. Therefore, this particular region should be carefully explored during primary repair and the central slip restored if possible. Failing this, the lateral bands should be approximated on the dorsum of the finger and sutured to prevent volar displacement. Immobilization of the finger in extension is also required.

Injuries to the extensor hood of the key metacarpophalangeal joints must be carefully sutured including the lateral expansions with their intrinsic insertions.

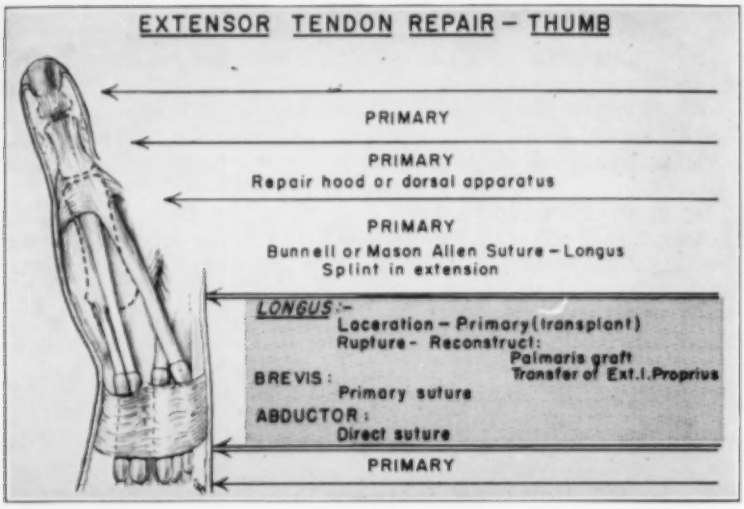

CHART IV

The long extensors interdigitate freely over the dorsum of the hand. This prevents retraction and primary repair is readily accomplished by coaptation and appropriate splinting with the wrist in extension. Distally, the splint is extended to include only the proximal phalanx. In all extensor injuries, the metacarpophalangeal joints should be maintained in slight flexion during the period of immobilization. This avoids the contractures and imbalance associated with prolonged splinting in hyperextension.

At the wrist the extensor tendons are grouped in six compartments under the dorsal carpal ligaments, each with a separate tendon sheath. When cut, they retract into the forearm. Primary repair is anatomically more difficult in this area. It must be accompanied by resection of the mucous sheaths and decompression of the compartments by longitudinally incising the dorsal carpal ligament at its attachment.

Chart IV demonstrates the anatomy of the extensor apparatus of the thumb and illustrates the appropriate operative procedures.

When cut over the base of the thumb, the long extensor retracts considerably and, due to angulation around Lister's tubercle of the radius, repair is made more difficult. Primary repair of the tendon in this area may require that it be rerouted subcutaneously to permit approximation of the ends without tension. At the tubercle of Lister, the tendon is subject to attrition and may rupture spontaneously, especially following Colles' fracture. With loss of tendon substance, secondary repair by transfer of the extensor indicis proprius, which lies to the ulnar side of the communis, is indicated. However, if the injury lies at or distal to the metacarpophalangeal joint, inadequate length of the proprius makes a palmaris graft more suitable.

Primary repair of the extensor pollicis brevis, which functions both as an extensor and abductor, is desirable but not always essential if the long extensor and abductor are intact. Isolated lacerations of the brevis cause little deformity and may not be diagnosed. Failure to repair the extensor pollicis brevis can result in incomplete extension of the proximal phalanx and slight imbalance of the hood mechanism.

The abductor longus presents no particular anatomical difficulty in primary repair. Repair is essential as it not only functions as an abductor, but also as a

stabilizer of the important metacarpomultangular articulation of the thumb.

SUMMARY

The hand has been divided into anatomical areas of injury so that specific problems in repair might be presented as clearly as possible.

Hand wounds, even those which on the surface appear trivial, must be evaluated with knowledge of underlying anatomical structures so that proper diagnosis and treatment can be instituted. Injuries to circulation, skin, skeletal structures, and nerve pathways demand definitive treatment in that order. Tendon injuries, although lowest in the scale of tissue priorities, challenge surgical judgment and skill more than does injury to any other tissue. The restoration of function to injured tendons demands careful planning in the anatomy and physiology of repair, proper surgical facilities, and the atraumatic technique pioneered by Dr. Sterling Bunnell.

Illustrations are presented to serve as a guide in primary treatment of severed tendons. The type of repair is dictated largely by the character and location of the wound. Simple wound closure followed by secondary reconstruction or grafting is often the procedure of choice, particularly in no man's land and the deep thenar area of the flexor mechanism. All extensors, as a general rule, can be repaired primarily, except where there is loss of tendon substance or skin coverage. In properly selected cases, the skilled hand surgeon may elect to carry out a more definitive type of repair as a primary procedure. It must be remembered that extensive dissection and additional exploratory incisions can be extremely hazardous in the injured and potentially infected hand, even under the best of circumstances. When primary treatment fails because of compromised circulation, infection, or scarring, the success of secondary reconstructive procedures will be jeopardized.

Secondary reconstruction of tendon function does not always imply tendon-grafting. The most conservative surgery which gives the best assurance of good function with the least risk should be used. Other operative procedures which should be kept in mind are: delayed suture, tendon advancement, tendon substitution or transfer, tendon-lengthening, tenodesis, and arthrodesis.

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Excision of the Greater Multangular Bone as an Adjunct to Mobilization of the Thumb*

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Limited motion of the thumb, from any cause, reduces the range of pinch and grasp and diminishes the effectiveness of the digits of the hand (Fig. 1-A). When handling large objects the thumb should be in a position opposite the index and long fingers. The adducted thumb may hold small objects by utilizing pinch between the tip of the thumb and the radial side of the index finger. Although a rigid thumb in proper position with a wide web is a useful digit for pinch and grasp, a mobile thumb with minimal fixation at the base has greater versatility. A mobile thumb will have flexible joints at its base, a wide pliable web between the first and second metacarpals, and sufficient motor power to stabilize the distal phalanx of the thumb against the other digits.

If the soft tissues or joint surfaces of the carpometacarpal and intercarpal joints at the base of the thumb are damaged, either directly by trauma (Fig. 2-A) or indirectly by injury to muscles or nerves in the forearm (Fig. 1-A), function of the entire thumb unit may be hampered. The carpometacarpal joint may become rigid with resulting adduction and external rotation deformity of the first metacarpal. It is essential, therefore, to prevent adduction contracture from occurring if possible but, if present, to mobilize the base of the thumb by whatever method fits the individual problem.

ANATOMICAL STUDY

Thirty hands of cadavera were dissected and the function and anatomy of the thumb joint were studied. It was noted that motion at the base of the thumb occurs at the carpometacarpal articulations between the greater multangular and the first and second metacarpal bones, and at the intercarpal articulations between the greater and lesser multangular and the navicular. The multangulometacarpal articulation is a loosely fitting saddle joint which permits motion of the metacarpal in three planes, including flexion and extension, through 60 degrees, abduction and adduction through 55 degrees, and a few degrees of rotation about the long axis of the metacarpal. The combined motions of this joint allow the thumb to be moved through an arc which runs from extension through abduction to flexion and back again. Opposition is the summation of all these motions. The intercarpal joints permit only a few degrees of motion which occur only after the limit of movement has been reached at the multangulometacarpal joint. From this point on the greater multangular and the first metacarpal move as a unit, sliding along the navicular which, in extreme opposition, angulates volarward.

Stability of the carpometacarpal joint is afforded only by its capsule which has small thickenings at irregular intervals and by the tendons on the radial side of the carpometacarpal joint[7]. The loose capsule permits the first metacarpal to ride up on the saddle-shaped articular surface of the greater multangular when the thumb is moved toward the fingers. On external rotation the metacarpal is pulled into the saddle-shaped concavoconvexity of the greater multangular. A well developed transverse interbasilar ligament between the first and second metacarpals serves to limit extreme rotation.

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FIG. 1-A

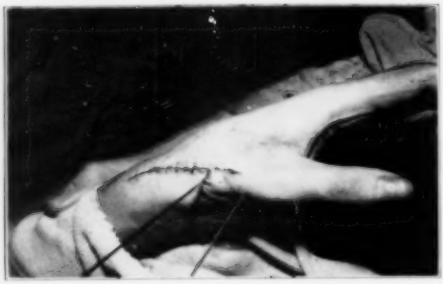

FIG. 1-B

Fig. 1-A: Thumb-web contracture with fibrosis at the carpometacarpal joint of the thumb. There was median and ulnar-nerve paralysis due to injury proximal to the elbow. The thumb could not be rotated and there was limitation of flexion. Adequate skin was present in the web area allowing partial mobilization, but the base of the thumb was tight and additional mobilization was necessary before opponens transfer could be done. Metacarpophalangeal joint flexion was severely limited and this precluded any consideration of arthrodesis at the carpometacarpal joint. Mobilization was attempted by arthroplasty.

Fig. 1-B: The hand at time of excision of the greater multangular and a portion of the first metacarpal. The incision was also used to release contracted structures at the base of the web. Tenotomy of the adductor tendon was done and the first dorsal interosseus was released from the second metacarpal shaft. Widening of the web was aided by two transfixing Kirschner wires which were used because of the firm contracture. Usually the wires are not necessary, as correction can be maintained with a plaster splint and compression dressing.

DEVELOPMENT AND TREATMENT OF ADDUCTION CONTRACTURE OF THE THUMB

Contracture of the thumb web may be the result of direct or indirect tissue injury with early formation of scar tissue which subsequently contracts and limits joint motion. Initially, unaffected joints may lose their elasticity and allow adhesions to develop across or around them as a result of prolonged disuse. The contracture may be either primary, resulting from direct trauma to the hand, or secondary, resulting from trauma to the forearm or shoulder with prolonged immobilization of the thumb in malposition:

1. Primary contracture of the thumb web and base of the thumb is due to direct damage to the structures between the first and second metacarpal bones. A deep burn, crush, or roller injury may cause direct necrosis of the tissue and hence

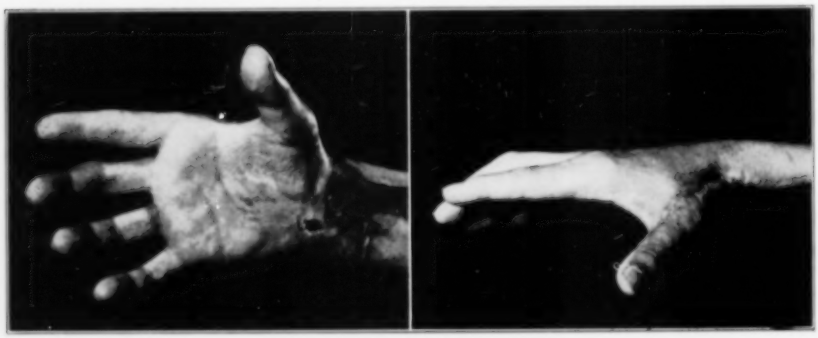

FIG. 2-A

This hand was crushed in a roller, resulting in severe damage to the base of the thumb and the volar aspect of the wrist and forearm. Thermal injury was present. The position of the thumb is fixed by fibrosis and joint adhesions. The volar skin was replaced by a thick split-thickness skin graft, the web space was released and, at a later time, the greater multangular and a segment of the first and second metacarpals were removed. Neither skin flap nor skin graft was necessary in the web. Moderate improvement followed but limited motion persisted at the metcarpophalangeal joint and at the distal thumb joint and this, of course, made additional mobilization at the base imperative.

FIG. 2-B

The roentgenograms at the top are the film prior to excision of the carpal bone and the film made immediately after the greater multangular was removed and the metacarpals were fixed with a Kirschner wire. The lower left roentgenogram shows impingement of the first metacarpal on the second, requiring additional bone excision for greater mobilization.

FIG. 2-C

Photographs showing ultimate appearance and function of the hand. The web space is adequate to allow thumb-to-index pinch. The base of the thumb was mobilized enough to allow thumb rotation to the long finger. It was necessary to perform tenolysis and tenotomy of the extensor pollicis longus at the time the last bone excision was done. This was followed by transfer of the extensor carpi radialis longus to replace this damaged extensor.

FIG. 3-A

Preoperative photographs made several months after this hand was crushed by a hot roller. The circulation was good, sensation was adequate, the thumb was adducted and rigid at the base, and the skin and fascia were contracted, along with intrinsic muscle fibrosis. Additional local therapy was necessary to get the skin cleaned for surgery.

the formation of fibrous tissue. Infection, if present, increases local and distant fibrosis. Direct injury to the small muscles of the hand, or to the recurrent branch of the median nerve at the thenar level, or damage to the motor branch of the ulnar nerve in the palm, will increase the tendency for thumb contracture. Even though soft tissues are stretched or the first metacarpal is maintained in a position of function, the duration of immobilization may allow development of fixed contracture between the first and second metacarpals and the multangular (Fig. 2-A).

2. Secondary contracture of the thumb web may follow injury to the forearm, arm, elbow, or shoulder. Vascular injury, nerve damage, and tendon and muscle fibrosis may allow secondary change to occur in the hand and around the thumb. Adduction contracture may develop if the thumb is not positioned away from the palm. Occasionally, a secondary contracture may reach a degree of fixation and fibrosis almost as severe as that resulting from a direct injury of the hand. Volkmann's ischaemia may cause a hand deformity which requires extensive surgery and splinting before functional correction is obtained [5].

The general principles for release of a contracture of the thumb web have been adequately established and emphasized by Bunnell, Howard, Littler, and Flynn. Two problems arise occasionally which are not solved adequately by simple soft-tissue release or capsulotomy at the base of the thumb with or without skin-grafting. In one situation (Fig. 2-A) there is adequate flexible skin in the thumb web, but limitation of motion results from contracture of the deep soft tissues with fixation of the base of the thumb which does not respond to release of the fascia and adductor pollicis muscle and capsulotomy. Under these circumstances arthroplasty at the base of the thumb by excision of the greater multangular and a portion of the base of the first or second metacarpal has allowed immobilization of the thumb (Figs. 2-B and 2-C).

FIG. 3-B

The preoperative roentgenogram on the left shows the first metacarpal in a fixed rigid position. The right roentgenogram indicates that the greater multangular and a segment of the navicular have been removed, along with part of the base of the second metacarpal. This was necessary for adequate mobilization. Note the difference in the distance from the radial styloid process to the base of the first metacarpal prior to excision of the greater multangular, and the close relationship of the two bones following excision. The thumb is shortened moderately by the procedure and this may affect the strength of pinch in certain instances, but this has not proved to be detrimental to over-all function.

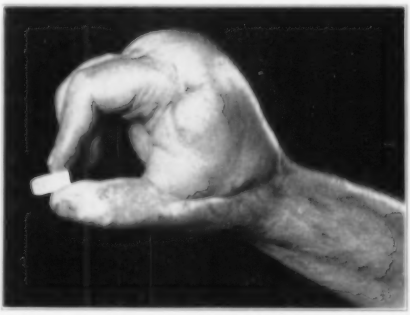

Fig. 3-C: Postoperative condition of the hand several months following initial release, application of pedicle flap, and partial amputation of the long finger. The pinch is weak, hook is fair, grasp is poor, and the appearance is improved. Sensation was good, and the hand was useful and superior to an artificial limb.

FIG. 3-C

In the second instance, fixation at the base of the thumb may be so severe that even complete soft-tissue release and the addition of new skin by either split-thickness skin graft or pedicle flap, will not allow adequate mobilization of the base of the thumb. Here the alternatives are either arthrodesis or arthroplasty. In our experience arthroplasty with complete excision of the greater multangular has proved satisfactory (Figs. 3-A, 3-B, and 3-C).

Gervis in 1949 reported excision of the greater multangular for treatment of monarticular osteo-arthritis of the multangulometacarpal joint. He indicated that with this procedure pain was diminished and the range of motion of the thumb increased and he implied that stability of the thumb was maintained. Osteo-arthri-

FIG. 4

Roentgenogram of patient with degenerative arthritis involving the first carpometacarpal joint and, to a lesser degree, the second carpometacarpal joint. Subluxation has occurred with sclerosis and destruction of the adjacent cartilage surfaces. At surgery, small exostoses were present and synovial inflammation was evident. The postoperative roentgenogram on the right shows absence of the greater multangular and a portion of the base of the first and the second metacarpal. The first metacarpal has migrated back to articulate with the navicular. Hand function is good, strength is good, pain diminished to absent, and the patient returned to work, weaving in a mill.

tis, in general, will not affect the surrounding skin and superficial fascia, but may have a moderate effect on adjacent tendons. Our limited but satisfactory experience with excision of the greater multangular for degenerative arthritis (Fig. 4) suggested application of this procedure to thumbs which had undergone fixed contracture as a result of direct or indirect trauma.

This communication reports the results of this procedure in twenty-two patients who have been followed for a minimum of one and one half years (Table I). The procedure is in reality an arthroplasty preserving some mobility in the thumb. In our experience the results from this operation have been superior to those following arthrodesis of the carpometacarpal joint of the thumb.

INDICATIONS FOR EXCISION OF THE GREATER MULTANGULAR

Degenerative Arthritis

Figure 4 shows the preoperative and postoperative condition of the multangulometacarpal joints of a hand with degenerative arthritis. Subluxation, narrowing of the joint space, limited motion, and instability were present. Pain was severe and necessitated cessation of work (Table I). Excision of the proximal end of the metacarpal may be necessary if the arthritic process involves the articular cartilage of the base of the metacarpal. In Patient 14 the gross specimen removed from the metacarpal base showed cystic changes with invasion of the metacarpal shaft by the synovial membrane. In spite of the large amount of bone removed the patient had good thumb stability with excellent range of motion and minimal discomfort. Pinch and grasp were good. The result is considered superior to that obtained following arthrodesis in a similar situation.

Traumatic Arthritis

Direct injury to the carpometacarpal joint with damage to the articular sur-

FIG. 5-A

FIG. 5-B

Fig. 5-A: Injury resulting from a close-range gunshot wound. Portions of extensor tendons, as well as most of the carpal bones, were blown out, along with a segment of the median nerve. Circulation to the thumb was good. It was necessary to amputate the index finger and a portion of its metacarpal.

Fig. 5-B: Roentgenogram of the hand several weeks following original injury. Note that the first metacarpal articulates with the radial styloid. The major carpal bones are absent as is a portion of the second metacarpal. In spite of this severe loss of bone there was still fairly good stability of the thumb.

FIG. 5-C

Photograph of hand following application of abdominal flap, excision of portion of the metacarpals, and tendon-transfer procedures to the thumb. Adequate function resulted and there was no pain at the base of the thumb. It was possible to get the thumb and long finger together for good pinch. It is our opinion that maintenance of motion allowed function superior to that which might have been attained by arthrodesis.

faces such as a comminuted fracture and subsequent articular incongruity has been treated satisfactorily by excision of the greater multangular and portions of either the first, second, or both metacarpals. These examples illustrate the advantage of excision over the alternate method of arthrodesis. The condition of the joints in these patients was comparable to that which might result from malunion of a fracture at the carpometacarpal joint, a fact which suggests that this procedure of exci-

TABLE I

Patient	Age (*Years*)	Sex	Injury (*Date and Type*)	Surgery Related to Thumb (*Date and Type*)	Figure in Text	Result in Thumb: Position	Result in Thumb: Function
1	18	M	10/52: crush-avulsion injury to right hand in corn picker; nerve injury, chronic oedema; multiple contractures; infection	9/53: division of fascia of thumb web and tenotomy of adductor pollicis; excision of greater multangular; split-thickness skin graft	7-A through 7-E	Fair	Fair: weak pinch and grasp; some rotation of thumb; hook
2	40	F	9/53: degenerative arthritis; pain and almost complete loss of motion at base of right thumb	2/54: excision of greater multangular		Good	Good: 90% of normal range of motion with minimal pain; returned to work
3	33	M	10/52: gunshot wound of right arm; deep scarring in hand and high median-nerve paralysis	5/54: section of fascia in web space and tenotomy of adductor pollicis muscle; excision of greater multangular bone; abdominal flap; tenolysis of extensors of thumb 9/54: lysis of median nerve and ulnar nerve in hand; opponens transfer		Good	Fair: fair pinch and grasp; moderate limitation of abduction of thumb; strength 30% of normal; sensation poor
4	29	M	5/53: gunshot wound of right wrist; thumb fixed in palm with severe adduction contracture of web; osteomyelitis of distal phalanx of thumb; no motion, thumb joints	5/54: division of fascia of thumb web and tenotomy of adductor pollicis; amputation of distal phalanx of thumb; excision of greater multangular; transfer of abdominal pedicle flap to thumb web 9/54: additional release of thumb web and revision of abdominal flap		Good	Fair: strong grasp; weak pinch; limitation of motion at base of thumb
5	35	M	12/54: compound fracture of right wrist with crush injury to hand and forearm; massive swelling and eventual intrinsic contractures of hand; no motion base of thumb and thumb metacarpophalangeal joint	5/55: division of deep fascia of thumb web and tenotomy of adductor pollicis; excision of greater multangular bone 11/55: transfer of abdominal pedicle flap to web space of thumb 4/56: defatting of flap		Good	Good: thumb mobile with good grasp; thumb abducts 3 inches from palm
6	26	M	5/54: high-voltage electrical burn with deep scarring of left forearm and hand; median and ulnar-nerve palsy in forearm	7/55: division of fascia of thumb web and tenotomy of adductor pollicis muscle 9/55: excision of greater multangular 11/55: transfer of ring-finger sublimis to thumb for opposition	1-A and 1-B	Good	Fair: wide pliable web space; pinch and grasp fair; fair rotation of thumb at base
7	24	M	3/54: high-voltage electrical burn of right forearm and hand; loss of ring and little fingers; median and ulnar palsy in forearm; deep soft-tissue loss of volar aspect of wrist and palm of hand	8/55: suture of median nerve at wrist; excision of greater multangular 2/56: transfer of brachioradialis to flexor pollicis longus with free tendon graft 5/56: disarticulation at wrist		Fair for thumb; remainder of hand poor	Poor: hand amputated because of poor sensation and poor function

8	40	M	12/55: crush avulsion injury to right upper extremity with severe compound fractures of hand, radius, ulna, and humerus; late deep scarring throughout hand; partial radial, ulnar, and median-nerve palsy; brachial plexus stretch injury	10/56: division of adductor pollicis tendon; section of fascia of web space of thumb; excision of greater multangular and portion of base of first metacarpal		Fair	Poor: amputation of hand because of poor sensation and function
9	44	M	5/56: crush injury to right hand in forging machine; loss of ring and little fingers and tip of thumb; deep scarring throughout hand	10/56: division of soft tissues of thumb web and tenotomy of adductor pollicis; excision of greater multangular; transfer of abdominal pedicle flap to thumb web	3-A and 3-B	Good	Fair: fair pinch and grasp; fair motion at base of thumb in all directions
10	28	M	7/55: hot-roller injury to right hand and forearm in steam press; multiple contractures of hand; base of thumb rigid	11/55: division of fascia of web space; tenotomy of adductor pollicis; excision of greater multangular 5/56: opponens transfer 9/56: excision of adjacent portions of the bases of the first and second metacarpals; transfer of extensor carpi radialis longus to extensor pollicis longus; tenolysis of abductor pollicis longus and extensor pollicis brevis	2-A, 2-B, and 2-C	Good	Good: pinch and grasp fair; motion 50% of normal
11	45	M	8/56: roller injury to hand and forearm with resultant severe adduction contracture of thumb in plane of palm; massive oedema of hand; partial radial, median, and ulnar-nerve palsy; dislocation carpometacarpal joints	2/57: division of fascia of thumb web and tenotomy of adductor pollicis; excision of greater multangular bone and two-thirds of base of first metacarpal	6-A through 6-E	Excellent	Good: thumb opposes ring finger and abducts 2 inches from palm
12	39	M	8/56: laceration of base of thumb; laceration of ulnar nerve at elbow; flexion-adduction contracture of thumb with flexor pollicis longus, main deforming factor; fair web space, but minimal motion at base of thumb	3/57: excision of greater multangular and adjacent portions of the first and second metacarpals		Fair	Fair: motion limited at base of thumb, 30% of normal; good motion, metacarpophalangeal joint
13	45	M	12/56: gunshot wound right forearm with radial-nerve paralysis, loss of substance of extensor muscles; fracture both bones; thumb in fair position but rigid at base	10/57: section of deep fascia; tenotomy of adductor pollicis; excision of greater multangular		Good	Approximately 50% of normal; thumb opposes ring finger, lacks long extensor
14	58	F	Degenerative arthritis, aching pain in left thumb for three years; severe limitation of motion, radial subluxation; other joints of hand affected	11/57: excision greater multangular and proximal segment first metacarpal		Excellent	90% of normal motion; pain relieved; stability, good result (superior to arthrodesis)

TABLE I—*Continued*

Patient	Age (*Years*)	Sex	Injury (*Date and Type*)	Surgery Related to Thumb (*Date and Type*)	Figure in Text	Result in Thumb	
						Position	Function
15	26	M	10/56: roller injury to right hand, loss of index, long, and ring fingers; thumb rigid; partial radial and median-nerve palsy in hand	4/57: deletion of second, third, and fourth metacarpals, lesser multangular bone, and soft tissues of thumb web; abdominal pedicle flap transferred to cleft between thumb and little finger 6/57: excision, greater multangular and ulnar half, base of first metacarpal		Good	Lobster-claw hand, no pinch; weak grasp, good push
16	40	M	10/56: crush injury to entire left upper extremity in hay baler; fracture, radius with non-union; fracture humerus; brachial plexus stretch palsy; median and ulnar hypalgesia; thumb tightly adducted with pliable skin	6/57: bone graft, right radius; excision distal third of ulna 10/57: excision greater multangular and part of first and second metacarpals; division of all fascia of thumb web; tenotomy adductor pollicis		Excellent	Range of motion approximately 70% of normal; still needs opponens transfer
17	50	F	/56: degenerative arthritis multangulometacarpal joint; pain; limited motion; left work because of pain	11/57: excision, greater multangular and ulnar segment of first metacarpal	4	Excellent	Full-time work as seamstress; no pain; good stability; 80% of normal motion
18	62	M	2/55: crush injury of right hand, forearm, and arm in waste machine; radial and ulnar-nerve palsy; hand functioned as hook; extension contracture of thumb	9/55: total carpalectomy of right wrist to mobilize wrist, correct flexion deformity, and to mobilize thumb		Good	Moderate motion at base; thumb weak; can grasp large objects
19	27	M	4/50: Volkmann's contracture left forearm following crush injury in truck accident; complete ulnar-nerve palsy; adduction contracture of thumb; rigid thumb at base	6/51: total carpalectomy, opening thumb web; deletion, little finger 11/51: opponens transfer		Good	Fair: pinch fair; fair grasp; motion 60% of normal
20	16	M	10/54: gunshot wound; carpal bones blown out, skin loss; first metacarpal articulating with radius	1/55: abdominal flap; deletion second ray; tendon transfer	5-A, 5-B, and 5-C	Excellent	Good: mobile thumb; 70% of normal motion; no pain; good stability
21	44	M	5/57: crush injury right hand in spokes of loom driving gear, with dislocation carpometacarpal joints; chronic oedema of hand; contracture of thumb web with fixation in external rotation away from palm; laceration, extensors of all digits	9/57: release of soft tissues of thumb web; excision, greater multangular and portion of first metacarpal; split-thickness skin graft to dorsum of hand and thumb web		Fair	Fair: now able to pinch, grasp, and hook; refused abdominal flap and extensor-tendon repair
22	40	M	2/57: crush injury to hand and forearm, extensors lacerated; wrist fusion necessary; rigid thumb	2/58: excision of greater multangular and base of first metacarpal; thumb web opened, split-thickness skin graft applied on dorsum		Good	Improved for pinch of small objects

sion could be utilized for improving an unsatisfactory result following fracture at the base of the thumb.

Correction of Contracture at Base of Thumb without Skin-Grafting

Fixation at the carpometacarpal joint as a result of direct or indirect trauma may prevent rotation, abduction, and flexion of the first metacarpal (Figs. 6-A through 6-E). Moderate contracture of the soft tissues in the web space may contribute to limitation of the joint but this is a secondary result rather than a primary cause. Adequate skin is present (Fig. 6-B) and does not require the addition of either a split-thickness skin graft or pedicle flap for widening the web space. Figure 6-A shows extreme limitation of motion in the thumb with inability to pinch, grasp, or oppose the thumb. The web was opened, the superficial fascia, deep fascia, and the adductor fascia were sectioned, and the origin of the adductor was stripped from the third metacarpal. The motor supply to this muscle was not damaged. Capsulotomy at the carpometacarpal joint was accomplished, but this would not allow complete rotation of the thumb. The cause of the limitation of motion was located at the base of the thumb and not in the more distal area between the first and second metacarpals. The greater multangular was removed in segments along with a portion of the base of the metacarpal. The postoperative roentgenogram (Fig. 6-D) shows the first metacarpal at its new point of articulation with the radial styloid, the base of the second metacarpal, and the lesser multangular. All the metacarpals had been dislocated and there was disorganization of the wrist bones but, since this was causing the patient minimal difficulty, arthrodesis of the wrist was not done. In spite of the fact that there was complete paralysis of the opponens muscle, the aberrant attachment of the palmaris longus and the presence of an abductor pollicis brevis made it unnecessary to do opponens transfer for opposition.

The condition of the hand eighteen months following original injury proved that arthrodesis of the thumb was not necessary; rotation and flexion were improved (Fig. 6-E).

If the web contracture and the contracture at the base of the thumb can be corrected without split-thickness skin-grafting or a pedicle flap, the advantage is obvious. Figure 2-A is the hand of a patient injured by a hot roller approximately three months prior to the time this photograph was made. The thumb was fixed in external rotation and abduction with only a few degrees of motion at the tip. Scarring was present at the base and there was contracture of the skin on the volar surface of the wrist and fascial contracture in the web space. There was also paralysis of the muscles supplied by the motor branch of the median nerve.

The soft tissues were released in the web but there was still fixation at the base of the thumb. This was partially improved by excision of the greater multangular and release of the adherent extensor pollicis longus which had been severed and had become fixed to the carpal bone. The range of motion improved enough to allow a tendon transfer for opposition. After several months there was no additional improvement in the range of motion at the base of the thumb. The roentgenogram in Figure 2-B shows impingement of the base of the first metacarpal on the second with resulting limited rotation. Note that in this patient the first metacarpal articulates with the navicular and not with the radius. Segments of bone were then removed from the ulnar aspect of the first metacarpal and the radial side of the second after which the range of motion was improved enough to allow the patient to oppose the thumb to the index, long, and ring fingers and to clear the palm with ease (Fig. 2-C). The combination procedure of release of soft tissue, excision of the greater multangular, and portions of the first and second metacarpals, with or without tendon transfer, proved to be a procedure of considerable advantage in treating this particular group of hands. Arthrodesis, with its rigid fixation, has been avoided and the inconvenience as well as bulkiness of the abdominal pedicle flap has been eliminated.

FIG. 6-A

FIG. 6-B

Fig. 6-A: This patient's hand was first seen about six weeks following severe roller injury. The thumb is rigid and fixed in external rotation and adduction. Damage had occurred to the carpal bones and there were unreduced dislocations of the metacarpal bones dorsally. This represents the maximum flexion of all digits.

Fig. 6-B: Side view showing fullness in the web space, limited wrist flexion, and fixed external rotation of the first metacarpal.

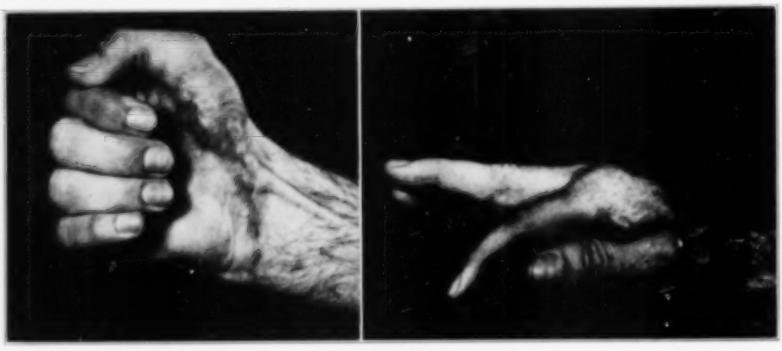

FIG. 6-C

Condition of the hand six weeks following elevation, splinting, whirlpool, and massage. Much of the oedema has subsided, the range of motion of the thumb has improved slightly, but it cannot be rotated or abducted and there is no useful pinch between the thumb and the tips of the other digits. There was lack of full extension of the index finger because of the damage and fibrosis of the extensor tendon.

Release of Contracture at the Base of the Thumb by Excision of the Greater Multangular in Conjunction with Split-Thickness Skin Graft

Severely damaged hands with multiple joint changes occasionally do not warrant use of the abdominal pedicle flap as an initial procedure. Figure 7-A shows a cornpicker hand following trauma and severe infection. After several months of treatment moderate sensation returned and a slight amount of motion was present in the digits. The hand served as a hook (Fig. 7-B). A portion of the little finger was amputated. The patient would not allow the use of an abdominal flap but he did consent to local treatment of the thumb web. The greater multangular together with a portion of the base of the second metacarpal was excised (Fig. 7-C) and a split-thickness skin graft was applied to the web after release of the soft tissues. Figure 7-D shows moderate increase in the range of abduction of the first metacarpal with the resulting flipper type of pinch. Abdominal flap, joint resection, and other procedures were indicated but not accepted. In spite of this the patient obtained a moderate pinch and still had a hook with sensation. Attempts to correct the claw hand in this situation would decrease function of the hand.

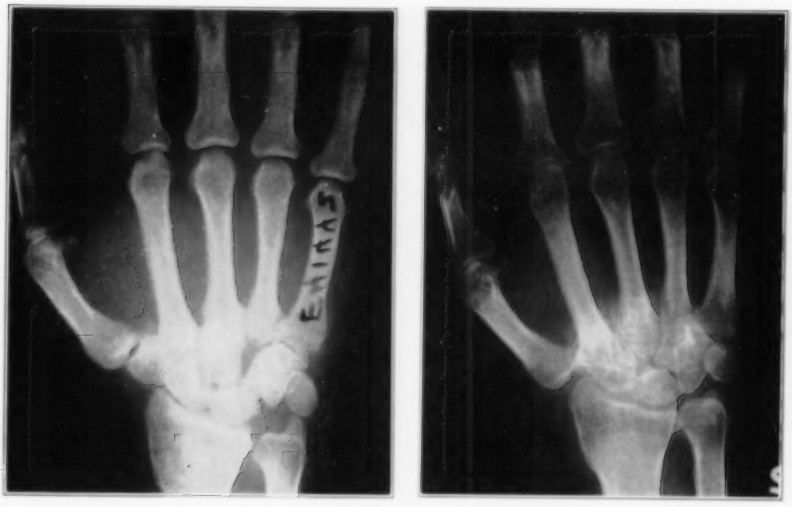

FIG. 6-D

Preoperative and postoperative roentgenograms showing disruption of the carpal and metacarpal bones. On the left, the greater multangular is in place and the thumb is fixed at the base. On the right, the greater multangular and a portion of the base of the first and second metacarpals have been removed and the first metacarpal is now articulating with the styloid process of the radius.

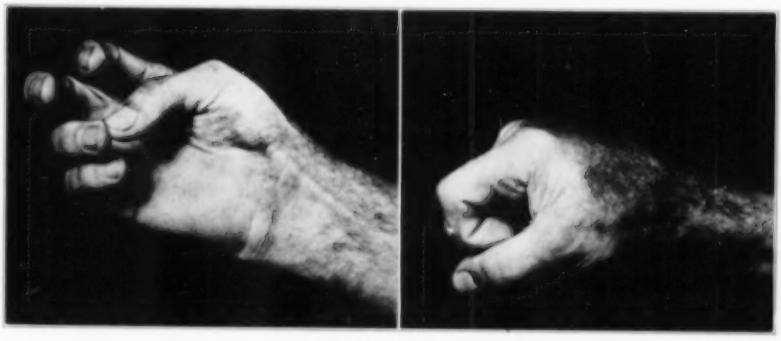

FIG. 6-E

Postoperative condition of the hand following soft-tissue release in the web, tenosynovectomy of the tendons at the base of the thumb, excision of the multangulometacarpal joint and postoperative plaster splinting and stretching. No additional tendon transfer or other surgery was necessary to restore the pinch and grasp of the hand. The aberrant palmaris longus improved the function of opposition.

Release of Contracture at the Base of the Thumb by Excision of Greater Multangular and Application of Abdominal Pedicle Flap

Fixation of the thumb web and its base may be of such severity that soft-tissue release and bone excision must be followed by abdominal pedicle flap to allow adequate mobilization of the thumb, improve nutrition to the base of the thumb, and gliding of the adjacent tendons. Figure 3-A shows a hand severely damaged by a hot roller. A split-thickness skin graft was applied to the dorsum of the hand and selective amputations performed. When the patient was first seen the rigidity of the thumb and adjacent fingers made use of the hand impossible. Sensation was present, however, and for this reason reconstructive procedures were carried out. The thumb web was opened widely from dorsal to ventral surface, the

soft-tissue contractures were released, and the greater multangular was removed with portions of the adjacent bones. Tenolysis of the extensor tendons and the abductor pollicis longus was performed. The roentgenograms before and after operation (Fig. 3-B) show the change in the position of the first metacarpal following excision of the greater multangular, the base of the second metacarpal, a portion of the lesser multangular, and a part of the navicular. All these bones had become one indistinguishable mass, and bone excision was continued until mobilization

FIG. 7-A

FIG. 7-B

Fig. 7-A: Hand showing the result of severe crushing injury in a corn picker with subsequent pyogenic infection. The thumb is already contracted in external rotation. The intrinsic muscles of the thumb have been damaged beyond repair. A long period of treatment was necessary following incision and drainage and removal of necrotic tissue. Fixation of the hand in a position of function was impossible because of changes which had already occurred.

Fig. 7-B: The hand several months after treatment was started. The ulnar nerve had been completely destroyed. The thumb is fixed in the base of the index finger with severe web contracture and fibrosis over the first carpometacarpal joint. No intrinsic muscles of the thumb were present and the clawing of the other digits was severe. Ideal reconstruction was impossible.

was possible. Following application of an abdominal pedicle flap (Fig. 3-C) the functions of pinch, grasp, and hook were restored to what was left of this hand.

Figure 8 shows a hand following traumatic amputation of all digits except the thumb. The thumb was rigid and useless but did have sensation. Resection of the greater multangular and the second, third, and fourth metacarpals allowed mobilization of the first and fifth metacarpals. An abdominal flap was used to cover the cleft. These procedures made this a helping hand which was supplemented, also, by a prosthetic hook and cable.

In another patient a close-range gunshot wound to the base of the thumb resulted in such rigid fixation that mobilization, even by pedicle flap and excision of the greater multangular, was not possible. Soft-tissue release was done, the greater multangular removed, and the first metacarpal placed opposite the index finger and held there with two Kirschner wires. An abdominal pedicle flap was applied. Fibrosis occurred but the thumb, in this fixed position, was adequate for pinch and grasp although not as satisfactory as a movable thumb. Two patients in the group under consideration had such severe fibrosis that mobilization could not be accomplished even by extensive removal of bone. Nevertheless, the procedure allowed the thumb to be repositioned easily and even though rapid fibrosis occurred the position of the thumb was improved and moderate improvement in function was achieved.

OPERATIVE PROCEDURE FOR WEB RELEASE AND EXCISION OF THE GREATER MULTANGULAR

The incision should allow access to all the structures in the space between the first and second metacarpals, as well as visualization of the navicular. The incision

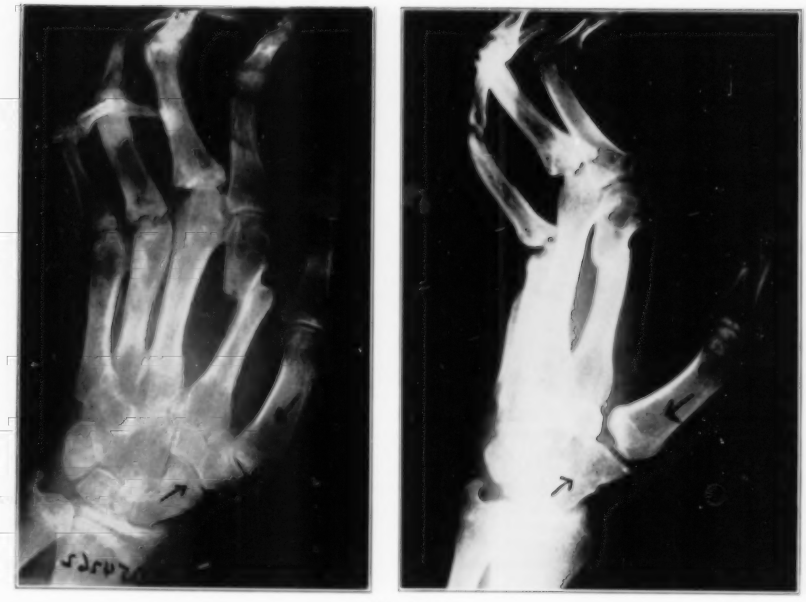

FIG. 7-C

Preoperative and postoperative roentgenograms showing relationship of the first metacarpal to the greater multangular and second metacarpal. The postoperative roentgenogram shows excision of the greater multangular and a portion of the lesser multangular. The first metacarpal has been allowed to migrate back to the navicular. Portions of the heads of the second and third metacarpals were removed and the little finger was amputated.

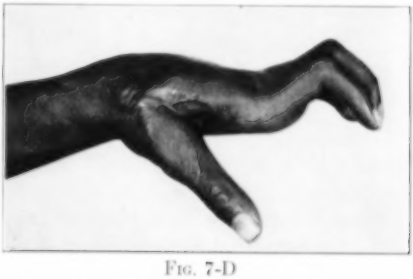

FIG. 7-D

FIG. 7-E

Fig. 7-D: A split-thickness skin graft has been applied in the web, but no effort was made to correct the clawing of the fingers. The hand was not satisfactory for application of a pedicle flap and, in addition, the patient refused to have his hand attached to the abdomen. The range of abduction improved following the bone and joint excision. Release of the web alone would not allow mobilization of the thumb.

Fig. 7-E: This photograph shows the patient's pinch and grasp. The major motion of the hand utilized the action of the thumb to the second metacarpal. This amount of motion was possible only by arthroplasty. Arthrodesis or rigid fixation at the base of the thumb would have given him no use of the hand insofar as thumb-to-side pinch was concerned, because of the severe contractures in the remainder of the hand.

is made parallel with the abductor pollicis longus and extends into the web space as far as necessary to release the soft tissues. The superficial fascia is sectioned. The fascia over the adductor, the adductor insertion, and the portion of the adductor coming off the third metacarpal are released. The dorsal branch of the radial artery and the sensory radial nerve are reflected toward the dorsum, the base of the first metacarpal is identified, and the periosteum and capsule are removed to expose first the metacarpomultangular joint and then the naviculomultangular joint. A small osteotome is used to split the greater multangular into three segments and these are

FIG. 8

The hand on the left was crushed and four fingers amputated by a machine. The base of the thumb was fixed in external rotation. The thumb muscles were adequate. The second, third, and fourth metacarpals were excised and an abdominal flap was utilized to cover the remaining tendon and bone tissue. The greater multangular and the base of the first metacarpal were then excised in order to mobilize the thumb. Mobility was essential here because of the limited motion at the metacarpophalangeal joint. The hand on the right shows a satisfactory grasp. Sensation returned to the flap and the strength of the thumb was satisfactory. Arthrodesis at the base of the thumb would have eliminated much of the use of the remaining hand.

removed. Ligaments with small segments of bone are resected with an osteotome from the base and ulnar aspect of the base of the first metacarpal. Part of the base of the second metacarpal is also removed if necessary. Tenolysis of the adjacent extensor pollicis longus and abductor pollicis longus is carried out. A piece of gelfoam is inserted into the joint defect. A Kirschner wire between the first and second metacarpals may be used to hold the thumb in a rotated abducted position if skin-grafting is necessary or if there is considerable contracture of the adjacent soft tissues. The skin is closed and a compression dressing applied combined with a plaster splint to maintain abduction and rotation. Immobilization is maintained for about two weeks.

SUMMARY

Excision of the greater multangular together with portions of the base of either the first, second, or both first and second, metacarpals has been used as an adjunct procedure in the mobilization of the thumb when it is limited by degenerative arthritis, arthrosis as a result of trauma, severe contracture at the base of the thumb as a result of direct injury, or contracture secondary to adjacent injury. Excision of the greater multangular and release of the soft tissues may be sufficient in some instances to correct all contracture, while in others a split-thickness skin graft or abdominal pedicle flap may be necessary to maintain full motion of the thumb web. Improvement in range of motion at the base of the thumb may usually be expected, although occasionally only limited motion may persist, even though there is improvement in the position of the thumb. In effect, the procedure is an arthroplasty, either increasing the range of motion at the base of the thumb or improving position of the thumb with or without increased range of motion.

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DISCUSSION

Dr. T. Campbell Thompson, New York, N. Y.: In 1949 W. Harvey Gervis reported on the Excision of the Trapezium for Osteo-arthritis of the Trapezio-Metacarpal Joint (J. Bone and Joint Surg., 31-B: 537-539, Nov. 1949) and stated that results were good in eighteen operations. Only one of Dr. Goldner's patients had osteo-arthritis. This patient had a good result, although pain was not completely relieved. Apparently this excision was designed primarily for the relief of pain rather than improvement of position and function. It is interesting to note that in the same issue (31-B), Lasserre, Pauzat, and Derennes of Bordeaux, France, described osteo-arthritis of this joint for which they recommended immobilization with a light plastic splint. G. M. Miller of London reported good results after arthrodesis. Perhaps the problem is similar to that encountered so often in the hip—a mechanically poor joint in bad position. Should it be treated by fusion, resection, or reconstruction? I doubt if anyone here would want to try to reconstruct a deformed or arthritic trapeziometacarpal joint but, as always, the main thing to keep sight of is the patient's complaint. Is it poor position and poor muscle power as seen in poliomyelitis? Is it pain as seen in osteo-arthritis, or is it primarily deformity and stiffness as seen in the severely injured hand? These problems are all different. Dr. Goldner and Dr. Clippinger have adopted excision of the greater multangular to the treatment of severely injured hands largely to correct position. Perhaps the gain in mobility is also helpful but this may be at the sacrifice of some strength.

In 1930 Dr. Ralph Fitch reported that in attempting to produce a fusion between the greater multangular and first metacarpal in a poliomyelitic patient, he produced a dorsal dislocation of the base of the first metacarpal. This resulted in such excellent position of the thumb that he subsequently did this procedure a number of times intentionally. This does several of the things that occur as a result of trapeziectomy without the rather tedious procedure of taking out the bone piecemeal. It shortens the thumb and puts it in a position of opposition. I do not say that I would advocate this procedure. I wonder if the authors could not have achieved the same results more accurately with less loss of power by careful osteotomy at the base of the first metacarpal. They did not mention pain as a complaint except in the patient with osteo-arthritis. Although the joint we are discussing is not a weight-bearing joint, I wonder if we can be sure that a pseudarthrosis will not become painful with constant use and perhaps the increased mobility might allow the deformity to gradually recur. Certainly their procedure is much simpler and quicker than arthrodesis and perhaps it will some day be used as commonly for a malady at the base of the thumb as the Keller procedure is for hallux valgus.

Dr. Goldner (closing): Dr. Thompson says that only one patient in this group was operated upon because of osteo-arthritis of the multangulometacarpal joint. Actually, there are five patients with osteo-arthritis who have had adequate follow-up. All were improved by excision of the multangular and a portion of the first metacarpal; pain had decreased and the range of motion had improved. In none was the strength considered to be normal as compared with the opposite hand, but because of the relief of pain, the strength was improved as compared with the preoperative condition.

Arthrodesis *versus* excision is one of the most important points discussed in the paper. The evidence indicates that excision is superior in every respect to arthrodesis. In 1952 three patients with arthritis of the multangulometacarpal joint were treated by arthrodesis of this joint, and all three have, at the time of writing, certain limitation which make function of their hands less satisfactory than the more recent group treated by excision of the greater multangular bone. Following arthrodesis, the thumb is virtually a post and dexterity decreases as age increases because of continued loss of motion at the metacarpophalangeal joint. The thumb is in the way when the patient attempts to lift flat objects or place the hand in a confined space. If no other method of treatment were available, arthrodesis would have to be acceptable. In our experience excision or arthroplasty at the base of the thumb, although not a perfect procedure, is a satisfactory one.

Dr. Thompson implies that the symptom of pain was not given as an indication for excision of the greater multangular. Pain was a major symptom in the arthritic hands, but a secondary one in the severe deformities following trauma. Loss of strength was no problem in the traumatic hands, because in all instances there was inability to pinch or grasp. Osteotomy was not practical in any of this group because web contracture still requires correction prior to, or in conjunction with, osteotomy.

The Carpal-Tunnel Syndrome

A Clinical and Anatomical Study*

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The so-called carpal-tunnel syndrome is a curious, painful affliction of the hands, occurring typically in the median-nerve distribution, developing progressively in the form of paroxysmal and usually nocturnal bouts of burning, aching discomfort, partially relieved by prolonged inactivity and completely relieved by division of the transverse carpal ligament.

The lesion has been well established as a clinical entity during the past ten years by the articles of Cannon and Love, Brain, Wright, and Wilkerson, Kremer, Gilliatt, Golding, and Wilson, and Phalen. These reports have convincingly demonstrated that symptoms are produced by compression of the median nerve as it courses through the carpal tunnel. There is, however, no unanimity of opinion as to its pathogenesis. Evidence of nerve compression is usually demonstrable when the disease is associated with previous carpal or radial fractures [2]; chronic tenosynovitis was reported by Phalen and Kendrick as predominant in their series.

The prevalence of the disease among housewives at or near the time of the menopause supports the hypothesis that some physiological change may render the nerve susceptible to compression at this particular period of life. Woltman and Schiller and Kolb have directed attention to its association with acromegaly, and to improvement in symptoms after irradiation or extirpation of the pituitary tumor.

On one point there seems to be general agreement: symptoms are often produced or aggravated by a sudden increase in manual activity. A portion of this study comprises a clinical and experimental investigation of the nature of the activity which predisposes to median-nerve compression. In addition, measurements of the median nerve and of the transverse carpal ligament have been made in an attempt to localize the site of compression and to afford an operative yardstick for evaluating evidence of compression in borderline cases. Incidentally, we have disclosed an unusual number of anatomical abnormalities and a suggestion of hereditary predisposition.

CLINICAL STUDY

During the past three years we have studied in some detail twenty-two cases of carpal-tunnel syndrome involving thirty-four hands. The disease was bilateral in twelve and unilateral in ten patients. It occurred almost three times as frequently in women, and half of the patients were between thirty and fifty years of age. Numbness and paraesthesia in part or all of the digital distribution of the median nerve were present in all but one, and night pain was significant in thirty-one of thirty-four hands. The effect of exercise on the symptoms was equivocal, making the discomfort worse in thirteen hands and less in thirteen. Thenar atrophy was found in twelve of the twenty-eight hands in which the condition of the thenar musculature was noted. Tinel's sign was positive in thirteen of twenty hands. Objective evidence of sensory deficit was less apparent, hypaesthesia being demonstrable in only nineteen of thirty-four hands. The tourniquet test of Gilliatt and Wilson was not conclusive, being positive in nine cases, negative in eighteen, and equivocal in four.

*This work was aided by a grant from the Hitchcock Foundation, Hanover, New Hampshire.

Three features are of particular interest since they throw added light on the etiology of this condition:

A. There was evidence in four of a familial trait.* In each instance one parent had a similar hand affliction and in one a grandparent also had median-nerve paraesthesia. We have found previous references to a familial predisposition in articles by Zabriskie, Hare, and Masselink describing thenar atrophy and paraesthesiae occurring in three sisters; by Phalen and Kendrick who noted the classic picture in a mother and daughter; and by Stephens and Welch who reported a family with typical median neuritis coursing through three generations.

B. There was a history of increased use of the hand prior to the onset of symptoms in fourteen, a finding which is consistent with other reports. However, in ten of these the character of the work suggested a pattern of exercise which predis-

FIG. 1

Carpal tunnel exposed, showing bulbous pseudoneuroma (arrows) tapering into proximal third of tunnel.

poses to the carpal-tunnel syndrome. Two patients recently had started to milk cows on a dairy farm. Three were engaged in shop work involving handling of objects on a conveyor belt, with the wrists repeatedly flexed. Two had undertaken gardening which involved considerable hand weeding and another had been engaged for the preceding year in automobile-body spraying in which he repeatedly pressed the trigger of a spray gun with the index and long fingers, alternately flexing and extending the wrist. One was a woman who, for a year prior to the onset of symptoms, had been ladling soup twice daily for about 600 students, holding the ladle between index and long fingers and flexing the wrist. Another patient had for three years prior to the onset of symptoms been doing kitchen work involving much stirring and ladling. A careful review of the mechanics of exercise established that almost half of our patients had been engaged for varying periods of time prior to the onset of symptoms in prolonged activity involving forceful flexion of the fingers with the wrist either held in flexion or moving through some range of flexor motion.

C. Another prominent finding in this series, which has been mentioned infrequently in previous reports, was vasomotor imbalance. Fifteen of twenty-five hands in which observations were recorded were found to have significant sensitivity to cold. In eight of these, vasospasm in the form of excessive sweating, color changes of the skin, or mild degrees of oedema was demonstrable. The presence of

* Verified by Dr. John Sibley through personal contact with the families involved.

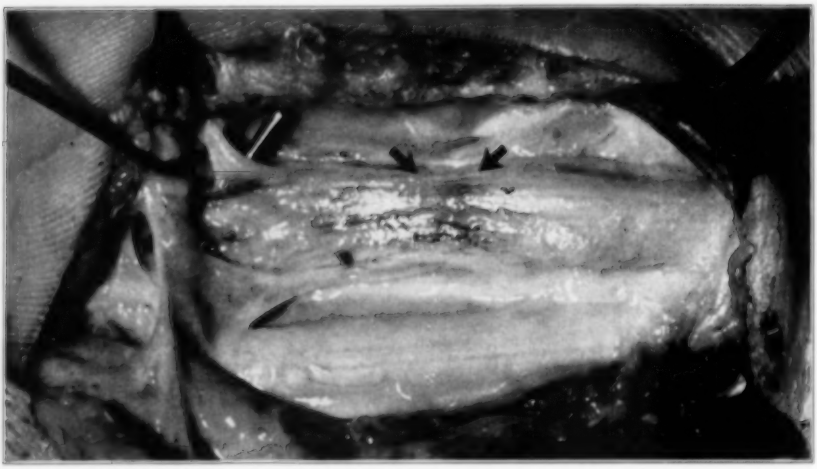

FIG. 2

Bandlike constriction of median nerve (arrows) at junction of proximal and middle thirds of carpal tunnel. (Motor branch isolated over nerve hook.)

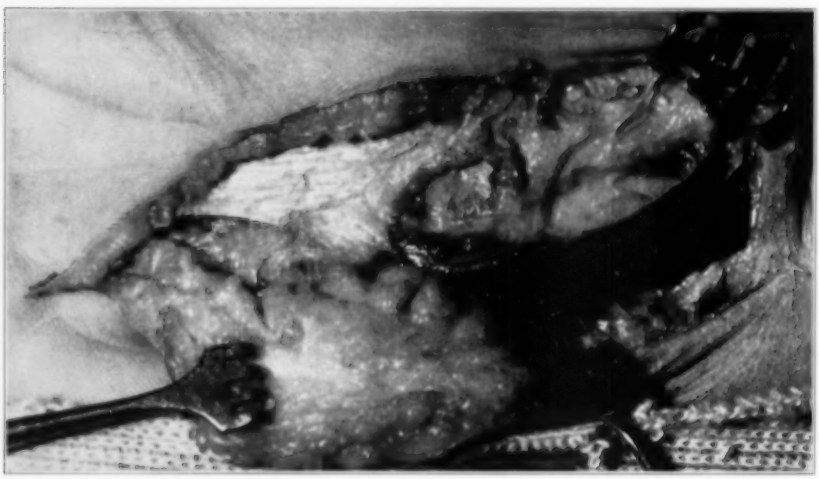

FIG. 3

Anomalous supplementary muscle at the wrist inserting into substance of abductor digiti quinti.

vasospasm in conjunction with median-nerve compression is certainly not unexpected and will probably be elicited more frequently by specific questioning.

OPERATIVE FINDINGS

Twenty-one hands in this series were subjected to surgical exploration. The carpal ligament was exposed and divided through a gently curving incision extending longitudinally over the ligament and prolonged when indicated along the distal wrist crease toward the ulnar side of the hand.

Operative exploration gave convincing evidence of one or more abnormalities in all but two hands, one of which displayed equivocal clinical evidence of the disease. Nine pseudoneuromata were found, in one instance having distended the nerve to a width of eleven millimeters. The enlargement of the nerve was sometimes pear-shaped, the bulbous portion lying proximal to the edge of the carpal

ligament while the smaller tapered portion extended into the proximal third of the carpal canal (Fig. 1). Definite nerve constriction within the proximal third of the canal was present in eight hands (Fig. 2). Adhesions about the nerve and tendons were considered significant in six. Moderate webbing of the bursal walls was thought to be pathological when noted in our first patients; this later was an almost constant finding in our autopsy studies.

One patient had a discoid, thick-walled cyst, 1.5 centimeters in diameter, arising from the posterior wall of the distal half of the carpal canal and containing thick, gelatinous material characteristic of a synovial cyst. In another, two discrete, encapsulated, thin-walled sacs, each measuring one centimeter in diameter, were found intimately attached to the periosteum overlying the lunate bone and containing a chalk-white, pasty material. Microscopic examination showed dense connective tissue and numerous deposits of calcium, suggesting the possibility of traumatic origin. The level of blood uric acid in this patient was within normal limits.

In another patient there was a thick-walled, encapsulated, tubular sac, five centimeters long and one centimeter in its greatest diameter, lying within the canal between the flexor digitorum sublimis and flexor digitorum profundus tendons and loosely incorporated in the wall of the ulnar bursa. The external surface was smooth and glistening; a central lumen contained a small amount of oily, amber-colored fluid. The dense connective-tissue stroma found on microscopic examination gave no clue to the etiology of this localized tenosynovitis. Three other patients, all of whom had pseudoneuromatous thickening of the median nerve associated with narrowing distal to the pseudoneuroma, revealed a tenosynovitis of the bursal wall within the carpal canal, with thickening and oedema of the membranes, excessive amounts of oily amber-colored fluid, but no evidence of a specific etiology.

A most surprising finding was the presence of congenital abnormalities in seven of the patients. In one instance the flexor digitorum sublimis muscle bellies extended almost completely through the canal. In two others exploration disclosed an additional muscle at the wrist arising from the antebrachial fascia just proximal to the carpal ligament and extending obliquely to the ulnar side of the hand to insert deep to the palmaris brevis in the substance of the abductor digiti quinti (Fig. 3). In both the palmaris brevis muscle was hypertrophied to two and three times its usual size. In three patients the palmaris longus was absent but this is probably not significant since the muscle is normally absent in 10 per cent of individuals. One wrist presented a thick fascial band extending from the antebrachial fascia across the ulnar artery and nerve to the pisiform bone.

EXPERIMENTAL OBSERVATIONS

A. Pressure Relationships within the Carpal Canal

The frequency of pseudoneuroma is presumptive evidence that, in at least some cases of carpal-tunnel syndrome, severe constriction of the nerve is produced near the proximal border of the ligament. Phalen and Kendrick emphasized the importance of wrist flexion in the production of median-nerve compression and have demonstrated that this motion, sustained for one minute, may reproduce painful symptoms. Meadoff injected lipiodol along the nerve sheath proximal to the carpal ligament and found that, with the wrist extended, flow proceeds into the palm, whereas wrist flexion offers an effective block to the progress of the liquid medium. Brain, Wright, and Wilkerson on the other hand felt that extension of the wrist plays a prominent role and carried out experiments with tambours in the carpal canal, which seem to indicate that wrist extension produces three times as much pressure as does flexion.

In an attempt to resolve these conflicting observations, the pressure within the carpal tunnel was recorded in six abnormal wrists during operation and in six normal hands studied at autopsy. After the carpal ligament had been exposed by a curved incision about the hypothenar eminence, which gave access to both ends of

PRESSURE INCREASE PRODUCED WITHIN *PROXIMAL* HALF OF CARPAL TUNNEL BY WRIST MOVEMENT

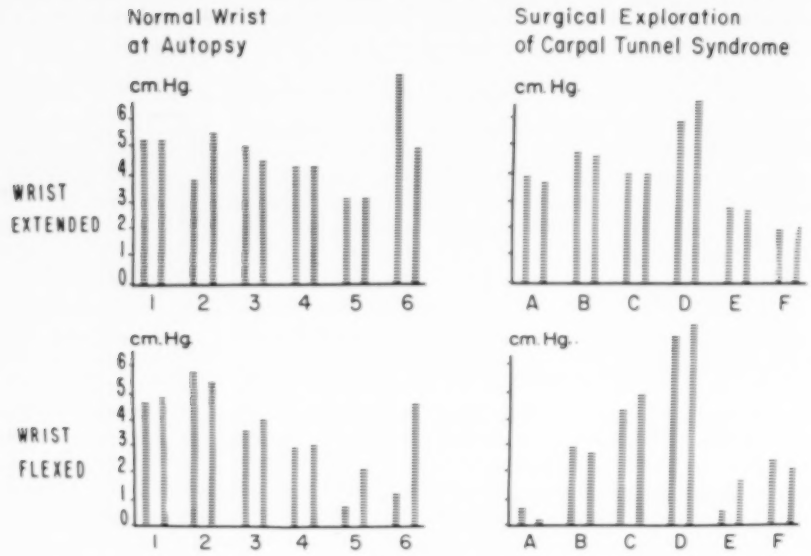
Normal Wrist at Autopsy
Surgical Exploration of Carpal Tunnel Syndrome
cm. Hg.
WRIST EXTENDED
WRIST FLEXED
0 1 2 3 4 5 6
1 2 3 4 5 6
A B C D E F

FIG. 4

PRESSURE INCREASE PRODUCED WITHIN *DISTAL* HALF OF CARPAL TUNNEL BY WRIST MOVEMENT

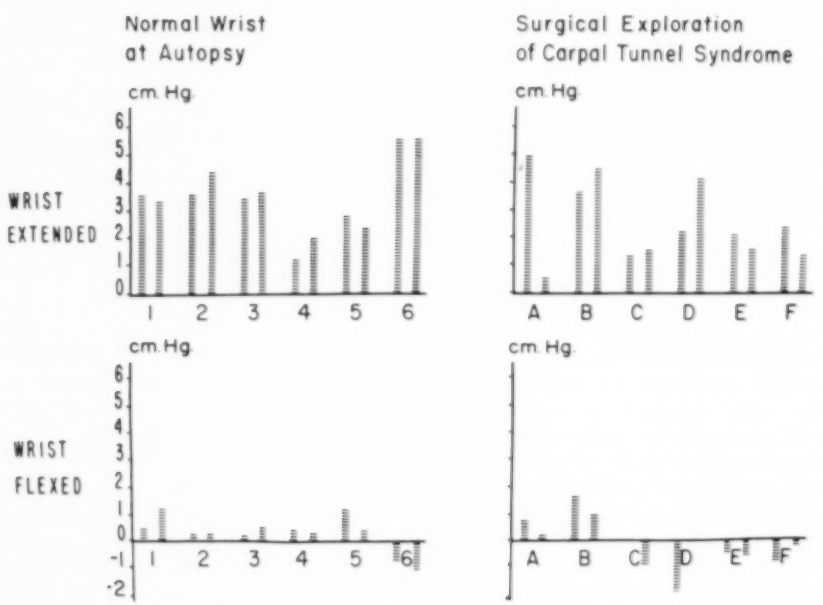
Normal Wrist at Autopsy
Surgical Exploration of Carpal Tunnel Syndrome
cm. Hg.
WRIST EXTENDED
WRIST FLEXED
-2 -1 0 1 2 3 4 5 6
1 2 3 4 5 6
A B C D E F

FIG. 5

the carpal tunnel, changes in pressure within the canal during wrist flexion and extension were determined. A No. 14 Foley catheter was connected to a manometer by a three-way stopcock and the entire system, including the distensible bag, was filled with mercury to the forty-centimeter mark on the manometer, a level which was found to create, by the weight of the mercury column acting through the open connector, enough distention of the bag to produce adequate excursion of the mercury column under the conditions of the experiment. For the observations made during surgery, the catheter was sterilized, after assembling the apparatus, by soaking in antiseptic solution. The procedure consisted in introducing the distensible bag, partially inflated with mercury, into the proximal half of the carpal canal, maintaining the manometer in a vertical position with its base held at the level of the wrist, and taking readings with the wrist in the neutral position, acutely flexed, and acutely extended, and then repeating the readings. Similar recordings were obtained after withdrawing the balloon and reinserting it in the distal half of the canal.

TABLE I

THICKNESS OF TRANSVERSE CARPAL LIGAMENT
(Expressed in Millimeters)

	Proximal Third	Middle Third	Distal Third
Autopsy Study			
Range	1.5 to 2.5	2.5 to 6.0	2.5 to 6.0
Mean	2.0	3.6	3.6
Carpal-Tunnel Syndrome			
Range	1.5 to 3.0	1.5 to 4.5	2.0 to 6.5
Mean	2.1	3.1	4.0

TABLE II

DIMENSIONS OF MEDIAN NERVE (Expressed in millimeters)

Case Number	Autopsy Study				Carpal Tunnel Syndrome			
	Proximal To Ligament	Proximal Third	Middle Third	Distal Third	Proximal To Ligament	Proximal Third	Middle Third	Distal Third
1	6.5x2.5	6.5x2.0	6.0x2.5	7.5x2.5	7.5x3.0	6.5x2.5	6.0x2.5	5.5x2.5
2	6.0x3.0	5.0x2.5	5.0x3.0	6.5x3.0	6.5x4.0	7.5x4.0	6.0x4.0	9.0x3.0
3	7.0x3.5	5.5x3.0	6.5x3.5	9.5x4.5	7.5x4.0	7.0x3.5	7.0x3.5	5.5x3.5
4	7.5x3.5	6.0x3.0	6.5x3.0	9.5x3.5	10.0x5.0	9.0x2.0	8.5x3.0	10.5x2.5
5	6.5x3.5	6.0x3.5	6.0x4.0	7.5x3.5	7.0x3.5	7.0x3.5	7.0x3.5	9.0x3.5
6	6.0x3.5	5.5x4.0	6.0x4.0	7.0x4.0	9.0x4.0	9.0x5.0	6.0x4.5	6.0x3.5
7	6.0x3.5	6.0x3.5	6.5x4.0	7.5x3.5	7.5x3.5	7.0x3.0	7.0x3.5	9.5x4.0
8	6.0x3.5	6.0x4.0	6.0x3.5	8.0x3.5	7.0x3.5	7.0x3.0	7.0x2.0	9.0x2.5
9	7.0x3.0	6.0x3.0	6.0x3.0	8.0x3.0	11.0x7.0	7.0x5.0	4.0x2.5	3.5x2.5
10	7.0x4.5	7.0x4.0	7.0x4.0	8.0x4.0	11.0x5.0	9.0x4.5	7.0x3.5	7.0x3.5
11	6.0x3.5	6.0x3.0	7.0x3.0	9.5x3.0	8.0x4.0	7.0x3.0	6.5x3.5	8.0x3.0
Range of Width : Range of Thickness	6.0 : 2.5 7.5 : 4.5	5.0 : 2.0 7.0 : 4.0	5.0 : 2.5 7.0 : 4.0	6.5 : 2.5 9.5 : 4.5	6.5 : 3.0 11.0 : 7.0	6.5 : 2.0 9.0 : 5.0	4.0 : 2.0 8.5 : 4.5	3.5 : 2.5 10.5 : 4.0
Mean	6.5x3.4	6.0x3.2	6.2x3.4	8.0x3.4	8.4x4.2	7.5x3.5	6.5x3.3	7.5x3.1

The results of the pressure studies are summarized in Figures 4 and 5. The variation between the two sets of readings in some cases indicates that the method is not always accurate, due presumably to changes in position of the bag during movement of the wrist. However, the findings, both in surgical and in post-mortem studies, suggest that a definite and roughly similar increase in pressure is produced within the proximal portion of the tunnel both by flexion and extension of

the wrist, while in the distal portion of the canal only extension raises the pressure. Flexion of the wrist is seen to cause either no increase of pressure within the distal part of the canal or else an actual reduction of pressure.

B. Mensuration of the Median Nerve and Transverse Carpal Ligament

In eleven wrists operated on for carpal-tunnel syndrome and in an equal number of wrists from consecutive autopsies upon adults, measurements were made at

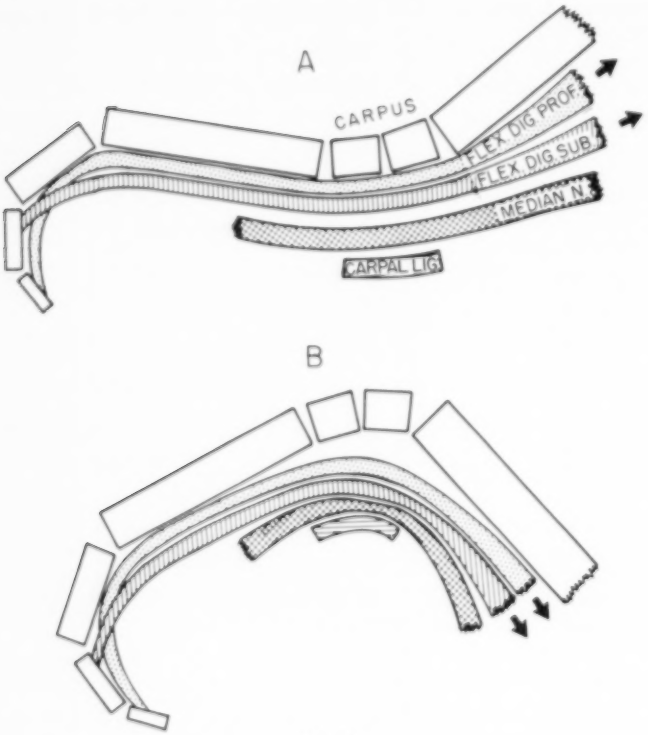

FIG. 6

Schematic representation of longitudinal section of hand, wrist, and lower forearm. *A*: With wrist extended and fingers forcefully flexed, the median nerve within the carpal canal is free of compression. *B*: With wrist flexed and long digital flexors under tension, the median nerve is compressed against the transverse carpal ligament.

various levels with calipers, recording the results to the nearest half millimeter. These measurements included the thickness of the transverse carpal ligament and the width and thickness of the median nerve.

Comparative measurements of the transverse carpal ligament are listed in Table I. The thickness of the ligament at various levels was essentially similar in both groups. In both groups the proximal third of the ligament was much thinner than the distal two-thirds. There was no indication from either the measurements or the gross appearance of the tissue that hypertrophy of the ligament played any role in the production of nerve compression.

The measurements of the median nerve recorded in Table II reveal several significant points:

1. The caliber of the median nerve in the autopsy specimens was found to be constant as far as the distal third of the carpal canal. At this level it became wider without change in its thickness just before branching occurred.

2. In the wrists operated upon pseudoneuromatous thickening of the nerve involved primarily the segment immediately proximal to the canal. However, in Cases 4, 6, and 10 widening of the nerve was still evident in the proximal third of the canal.

3. In the wrists operated upon there was a marked individual variation in the size of the median nerve. Some showed no measurable changes in caliber while others, such as Case 6, showed evidence of oedema of the nerve without measurable constriction. A third group, including Cases 4 and 9, showed the most advanced stage in which a pseudoneuroma was associated with definite atrophy of the nerve beyond the point of constriction, as indicated by the diminution in thickness of the nerve in the middle and distal thirds. These measurements do not pinpoint a particular level at which a reduction in thickness first occurs, but they are consistent with observations made on the other cases not included in this detailed study, in which constriction was found predominantly in the proximal third of the carpal canal. The instances of diminution in thickness of the median nerve in the middle and distal thirds of the canal represent atrophy associated with compression at a higher level and should not be misinterpreted as being the result of direct compression.

DISCUSSION

Our study of the occupations of a series of patients with the carpal-tunnel syndrome suggests that wrist flexion is more significant in the production of symptoms than extension as proposed by Brain, Wright, and Wilkerson. It seems probable that the inciting motion in many cases is repeated forceful flexion of the fingers, with the wrist acting in at least a slight degree of flexion. This conclusion is based on a logical anatomical concept: when the fingers are flexed with the wrist in extension, the flexor tendons are pressed against the posterior wall of the carpal canal; finger flexion with the wrist flexed squeezes the median nerve between the taut flexor tendons within the canal and the unyielding anterior wall and proximal rim of the carpal canal with a force proportional to the degree of grasp exerted by the digits (Fig. 6). Kendall appreciated the importance of tension of the flexor tendons of the fingers in his thoughtful study of this disease and Love noted three occupations which he thought might have contributed to the development of median neuritis in his series, namely, "very busy secretarial work, milking of cows by hand, and tailoring," all of which may fit into the action pattern we have described.

One may notice an apparent inconsistency between the clinical findings emphasizing the importance of wrist flexion and the experimental studies which show the diffuse nature of the pressure increase within the carpal canal caused by wrist extension. This inconsistency is resolved if one assumes that the most significant feature of the pressure studies is the increased pressure in the proximal half of the carpal canal produced by both flexion and extension of the wrist. This increased pressure during both wrist motions, combined with the anatomically explainable compression of the median nerve during wrist flexion, offers an explanation of the usual finding of compression of the median nerve in the proximal third of the carpal canal.

Evidence is accumulating that there is some kind of predisposition to this syndrome, the nature of which is still speculative. If repeated finger and wrist motion were the only factor, one would expect the disease to be much more frequent among manual workers whose occupation produces constant friction on the nerve. The verified history of a familial trait in four of our patients suggests that the predisposing factor may be an inherited one. The finding of anatomical abnormalities in or about the proximal aspect of the carpal canal in one-third of our surgical explorations suggests that, in some cases at least, anatomical variations may make the median nerve unusually vulnerable to conditions of stress which would be symptomless under other circumstances.

SUMMARY

A study of the occupations in twenty-two cases of carpal-tunnel syndrome involving thirty-four hands suggests that repeated, forceful flexion of the wrist and fingers is frequently a precipitating factor.

Hereditary predisposition and regional congenital abnormalities may also contribute to the development of median-nerve compression.

Quantitative measurements of the median nerve and transverse carpal ligament in wrists operated upon for the carpal-tunnel syndrome and in normal hands at autopsy have been compared. There is no evidence that hypertrophy of the transverse carpal ligament plays a role in the production of compression of the median nerve. Pseudoneuroma involves the portion of the nerve lying proximal to the ligament, but occasionally extends into the proximal third of the carpal tunnel where any demonstrable constriction of the nerve is usually located.

Studies of the pressure developed within the canal during wrist movements show that increased pressure develops in the proximal half during both flexion and extension of the wrist, whereas the distal half of the canal develops increased pressure during extension only.

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Dupuytren's Contracture

A New Concept of the Pathogenesis Correlated with Surgical Management *

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This important entity, known now for more than a century as Dupuytren's contracture, is controversial and incompletely understood except for the diagnosis. There are broad differences of opinion in etiology, pathogenesis, and therapy. A plan of therapy, based upon a new concept of the pathogenesis, to be herein presented, has been associated with superior results achieved with decidedly less stress for both patient and surgeon than was experienced by the routine use of radical aponeurosectomy.

This study of Dupuytren's contracture, palmar and plantar, has been pursued since 1936. During the first half of this period the pathological anatomy and etiology were investigated; during the second half the principal interest has been a correlation of pathogenesis and therapy [17].

Evidence will be presented to support the concept of the pathogenesis herein described, and it will be contended that this concept forms a sound basis for surgical management. In this therapeutic program conservative surgical techniques, including subcutaneous fasciotomy, are emphasized.

CLINICAL PICTURE

The incidence of Dupuytren's contracture is much higher in men than in women. While published statistical reports vary widely, a summary of the literature of reported cases indicates that the ratio is approximately seven men to one woman. While the onset of typical cases may develop any time after the second decade of life, the resulting nodules occasionally lie dormant so that there is little contracture and little disability until a later decade. In this series of 154 cases, the oldest patient was eighty-five years old and the youngest twenty-one, with the average being 56.5 years for men and 61.1 years for women. There were 130 men and twenty-four women, a ratio of 5.4 to one. In thirty-six patients (23.4 per cent) there was a definite hereditary factor, as indicated by the presence of the disease in other members of the same family.

The initial symptom was usually one or more nodules in the ulnar half of the palm, or the volar aspect of the proximal one-half of one or more fingers. A nodule beneath a transverse crease may remain flat and poorly defined or bulge out like twin nodules on each side of the crease. With the passage of time involution occurs, the nodule tends to flatten, and the associated proximal cord becomes rounder and larger. As nodular involution progresses, cords and contractures evolve. The right hand was involved in forty-two patients and the left in eighteen, while in ninety-four patients the disease was bilateral. (Surgery was bilateral in fifty-two.) Pain was seldom a symptom, although occasionally there was slight to moderate pain and tenderness at the sites of nodules. In the rare occasions when pain became a disabling symptom, it took the form of a steady ache or a drawing sensation. Hyperhidrosis of the palms was an occasional finding and was interpreted as a reflection of anxiety. Grasping of hard objects was avoided

*This has been a continuing study. Parts of the paper have been read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., January 1950, and the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January, 1952.

when the hands were sensitive. There were episodes, in seven patients, of either spasm or occlusion of a coronary artery.

CONTRACTURES

Flexion contractures of the fingers created most of the disability and had their highest incidence in the little and ring fingers. Involvement of the thumb and thenar eminence, while not the rule, was relatively common; contracture of the index finger was the least common. With advancing flexion contractures, the patients who were craftsmen, surgeons, or musicians became increasingly handicapped and many were forced to give up their trade or profession until the contractures were corrected. Involvement of the right hand frequently led to embar-

FIG. 1

The principal sites of nodules in palmar Dupuytren's contracture. The connecting black lines represent fascial cords.

rassment in shaking hands; more pronounced involvement led to sticking the finger in the eye when washing the face and difficulty in gloving the hand. As the contractures became yet more advanced, golf and other games were denied the patient. The rate of contracture proved extremely variable. There were instances when a finger became sharply flexed by the contracting nodules within a few months' time; in others the process of involution was so protracted that a period of many years was involved. The actual contracting process generally occurred by irregular steps, interspersed by periods of quiescence. At any time, the active disease process can come to a halt and remain unchanged for long periods of time —even for the remainder of the patient's life.

In this study the contractures are divided into three grades: Grade I contractures are those from 5 to 30 degrees; Grade II contractures are those between 31 and 60 degrees; and Grade III contractures represent contractures from 61 to 90+ degrees. The grade given to a hand is based upon the joint having the greatest degree of flexion contracture. In the classification devised by Meyerding

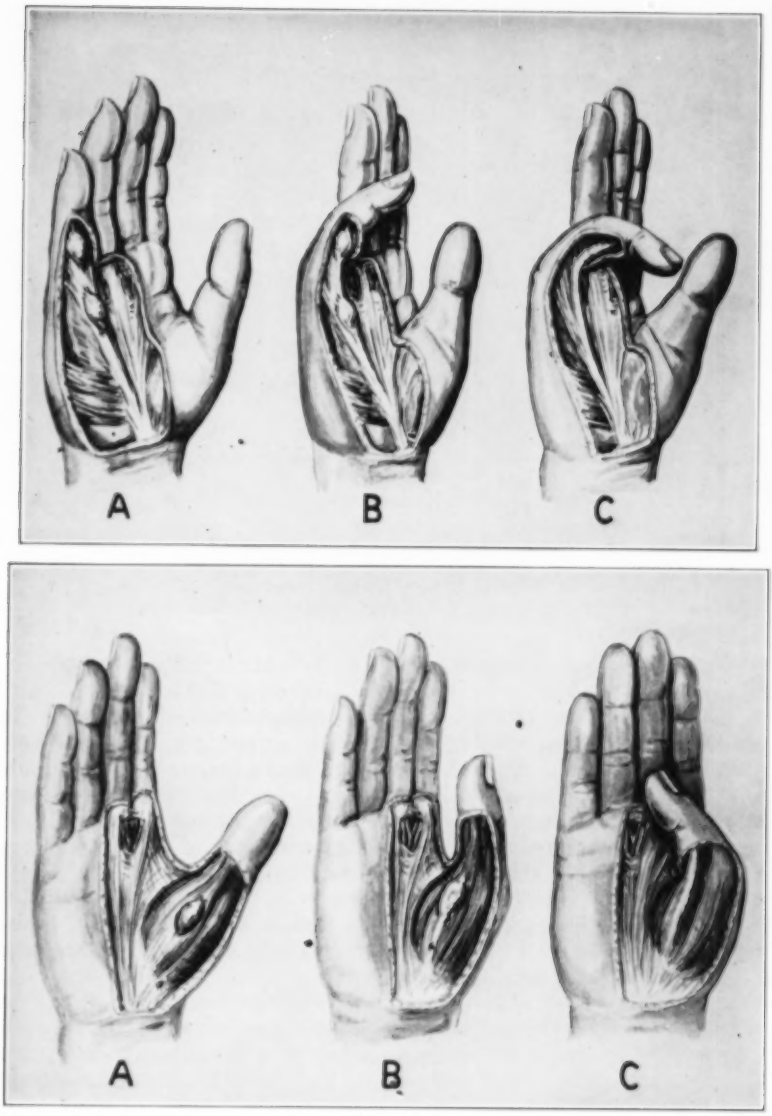


FIG. 2

Pathogenesis of Dupuytren's contracture showing three stages: *A*, the proliferative stage; *B*, the involutional stage; and *C*, the residual stage.

and associates, account was taken of the number of fingers involved and the degree of general disability. The classification of degree of contracture presented here has simplicity in its favor which is highly desirable when dealing with the more complex patterns of contracture. Of the 154 patients, there were no contractures in twelve (nodules only); first-degree contractures in twenty-two; second-degree, in forty-nine; and third-degree, in seventy-one.

ETIOLOGY

The etiology of Dupuytren's contracture continues to elude us. Investiga-

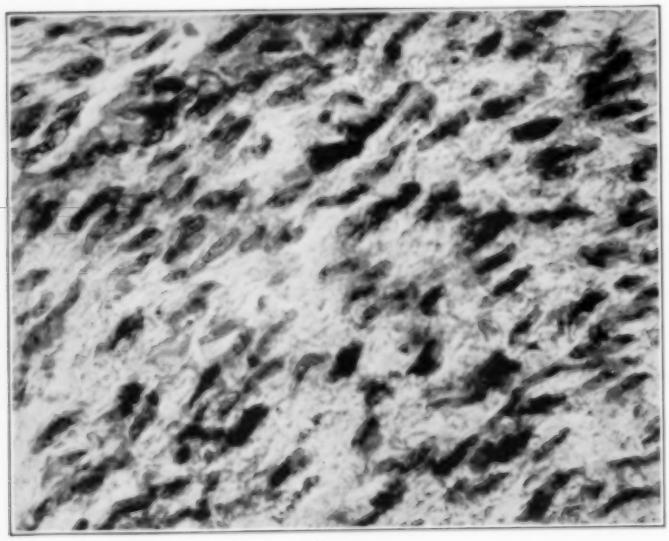


FIG. 3

Photomicrograph showing the cellular character of the proliferative stage. Nodules in this stage must not be misinterpreted as fibrosarcoma.

tions over a period of more than 100 years have failed to identify the true cause of this disease. Trauma appears to head the list of factors that are said to contribute to the disease. Actually, trauma has been variously credited as the sole cause of the disease, as only a contributing factor, or as playing no part whatsoever. Contemporary investigators, for the most part, credit trauma as being capable, at most, of being an aggravating factor, but not capable of causing the disease. Skoog presented the most comprehensive study of this concept. Many patients in the series herein reported gave a history of an accentuation of the flexion contracture following trauma to established nodules in the palm and fingers. While the trauma appeared to cause the contractures to evolve earlier, it probably did not materially influence the degree of contracture that ultimately would have evolved without specific trauma. Of the 154 patients, fifty-three did hard manual work, and 101 did light manual or sedentary work.

The hereditary factor is the most definite and best established of all potential etiological factors. The proportion of the total cases in which the hereditary factor was clearly noted varied in the different reported series from an insignificant percentage to an impressive 40 per cent [22]. In this series, a hereditary factor was evident in 23.4 per cent of the patients. The number of other alleged etiological agents that were found in association with this disease is legion. It may ultimately be disclosed that many factors, acting singly or in combinations, are capable of setting in motion the sequence of events which lead to Dupuytren's contracture in an individual so predisposed.

Identification of the fascial fibrogenic nodule as the essential lesion of this disease, in addition to the propensity of the nodule for recurring after incomplete removal (in the proliferative and early involutional stages) would appear to favor the neoplastic theory. Histologically, the nodule has a fibromatous-like appearance during the proliferative stage. It is tempting to consider the disease as a fascial dysplasia. In considering neoplasia as against dysplasia, the dividing line is by no means sharp.

It is my belief that neither chronic inflammation, nor trauma, nor neurological or psychological factors represent primary etiological agents in this disease.

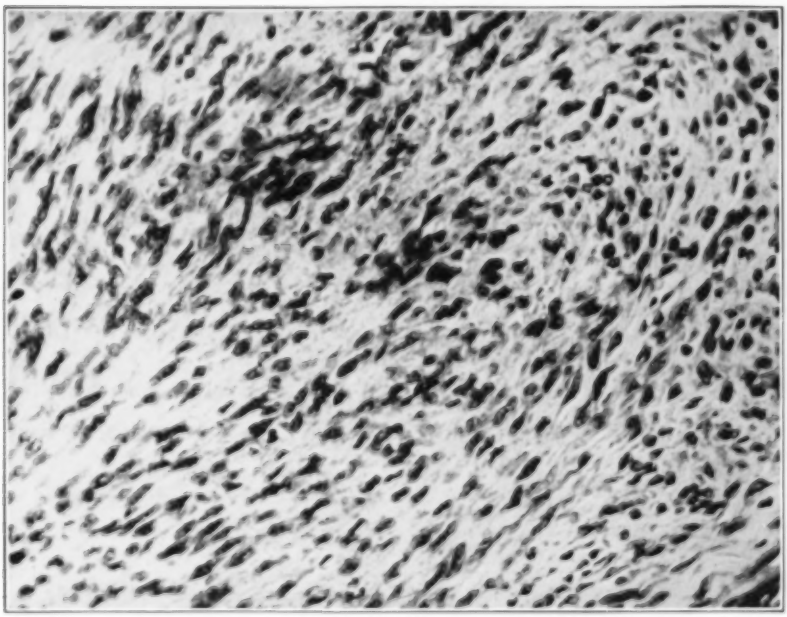


FIG. 4

The cells are beginning to align themselves with the major lines of mechanical stress. This change and the increase in collagen usher in the stage of involution.

PATHOLOGICAL ANATOMY AND PATHOGENESIS

The interpretation of the pathological anatomy of Dupuytren's contracture and the concept of the pathogenesis evolved from the meticulous study of tissues from more than 200 hands and twenty-eight feet involved by Dupuytren's contracture. While the etiology of this entity continues to elude us, much of the pathogenesis is becoming increasingly clear. An understanding of this aspect of the disease is decidedly helpful clinically in both non-operative and surgical management. In nearly all of the cases reported in this study, the operative procedure through which the pathological tissue was made available for study, was carried out by me, thus affording an opportunity to study both the gross and microscopic characteristics of the involved tissues. The initial and essential lesion in Dupuytren's contracture is a focus of proliferating fibroblasts (Fig. 3). While, grossly, a focus may exist as a solitary lesion in the palmar or plantar fascia, multiple foci are the rule. In most instances, the fibroblastic focus creates a palpable nodule. The fibrous cords, so prominent in this entity, form subsequent to the development of the nodule and are intimately related to the involution of the nodule. All the tissues identified with Dupuytren's contracture will be classified as (1) the essential fibrous nodules, (2) reactive tissues, and (3) residual tissues.

For descriptive purposes, the pathogenesis of Dupuytren's contracture will be divided into three stages: the proliferative stage, the involutional (contracting) stage, and the residual stage.

The Proliferative Stage

The nodule, whether it is one millimeter or several centimeters in diameter, is histologically a focus of fibroblasts which, in the proliferative stage, resembles a fibroma. At the onset, when the fibroblasts are young, the cells form a large portion of the tissue and the collagen a minimal portion (Fig. 4). In this focal fibroplasia, the fibroblasts do not align themselves with lines of stress and have,

FIG. 5

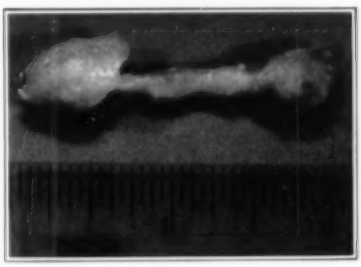
Photomicrograph (× 12) showing a palmar nodule in the early stage of involution. The arrow and broken lines point to the proximal small fascial cord in which there is early reactive hypertrophy.

in fact, no purposeful arrangement. There may be a solitary or multiple nodules appearing at various locations in the palm and fingers, and in the sole of the foot (Fig. 1). What might well be termed conglomerate nodules are rarely seen. These are made up of multiple nodules which coalesce and form a plaque. Such a plaque, in the hand, generally involves the ulnar half of the distal palm, and, in the foot, the medial aspect of the plantar fascia. A nodule in its early stage is rather resilient and even soft; later it becomes firm or hard.

While the nodules appear to originate in, or superficial to, the palmar fascia, they expand toward the surface, principally between the skin and the fascia. This creates a protruding mass easily identified by the palpating finger. A nodule having its origin either in, or directly adjacent to, the fascia or aponeurosis, attaches securely to this structure. Growth, by expansion, toward the surface generally causes the nodule to replace subcutaneous adipose tissue, and attach to the deep layers of the skin. At a later stage the nodule may replace or displace deep layers of the skin. Thus, with a deep attachment to the palmar aponeurosis and a superficial attachment to the under surface of the skin, the stage is set for the contraction of the involutional process to create a reactive fibrous cord. In the proliferative stage, the nodule is likely to be rather vascular and the considerable reactive tissue at the periphery appears partly related to the blood vessels supplying the nodule. It is not to be assumed that the nodules are limited to the distribution of the palmar and plantar aponeuroses. Actually, nodules frequently appear on the borders of the hand and in the webs, and are relatively common in the thenar eminence. A high incidence of nodules was observed on the volar aspect of the fingers, particularly over the volar aspect of the proximal interphalangeal joints and at the base of the fingers. In only two cases were nodules found distal to the proximal interphalangeal joint, and no typical nodules were seen on the dorsum of the fingers or the hand with the exception of knuckle pads (dorsal nodules) over the proximal interphalangeal joints (Fig. 25). In the foot, the nodules most frequently develop in the medial aspect of the plantar fascia, in its distal one-half. No nodules have ever been identified in relationship to the interphalangeal joints of the toes.

The Involutional Stage

In this stage, the fibroblasts of the nodule align themselves with the major lines of stress that pass through the nodules (Fig. 4). This is predominantly in the longitudinal axis of the hand or foot. As the cells become more mature and smaller they decrease in number, and the proportion of collagen steadily increases. It is during this process that contraction occurs. Actually, this involution, associated as it is with contraction of the nodule, is the process that creates the most prominent aspect of the clinical picture—the flexion contractures of the palm and fingers. As the process of collagenization and contraction evolves, the nodule becomes smaller in diameter and in so doing draws in or puckers the surrounding skin. In addition to its fixation to the overlying skin, the nodule may become anchored to an underlying tendon sheath or joint capsule. In the palm this process creates a skin contracture and at the same time increases tension stresses on the small band of fascia extending from the nodule to the apex of the palmar fascia. If, for example, a nodule is over a metacarpophalangeal joint, the process



A reactive fibrous cord (hypertrophied fascia) extending between two nodules in the involutional stage. (A cord develops proximal to each nodule, frequently creating a chain.)

FIG. 6

of the contracture draws the metacarpophalangeal joint into flexion. It does this because the line of least resistance would be flexion of this joint. The innumerable attempts to extend the metacarpophalangeal joint subject the narrow band of fascia extending to the apex of the aponeurosis to intermittent tension stresses. Out of this investigation has come the conclusion that the cord of Dupuytren's contracture forms, for the most part, proximal to the nodule and represents reactive functional hypertrophy in response to the repeated tension stresses on the band of fascia from which the nodule took its origin. The nodule, together with its proximal fascial cord, will be referred to henceforth as a nodule-cord unit, because the more usual picture in Dupuytren's contracture of the hand is that of multiple nodule-cord units united to form chains of nodule-cord units (Fig. 1). Contractures, in this disease, take place only within the nodules and from the involution of these foci of fibroplasia. No contracture appears to occur in the fascial cord—only hypertrophy. Further support of this concept came from the observation that contractures of interphalangeal joints occurred only when nodules developed in relation to these joints. There is absolutely no evidence that involvement of the palm has any influence whatever in causing flexion contractures of the interphalangeal joints of the fingers. The only contractures that involvement of the palmar aponeurosis can create are contractures of the metacarpophalangeal joints. A nodule located in the vicinity of the two transverse creases of the palm creates, during its involutionary process, a reactive fibrous cord proximal to the nodule, extending to the apex of the palmar fascia. If a nodule develops directly over, or nearby, the volar aspect of the proximal interphalangeal joint, the involution of the nodule can draw the interphalangeal joint into a flexion contracture. In doing so, a reactive proximal cord appears and extends from the nodule overlying the proximal interphalangeal joint to the base of the finger. There the fascial cord ends, unless there is a nodule in the palm in line with this cord. If so, the cord from the nodule in the finger joins the nodule-cord unit of

FIG. 7

Photomicrograph showing moderately advanced involution in a nodule. The triangular, central cellular area of this nodule is the last to involute.

the palm, and upon complete involution of the nodules, leaves a residual fascial cord which is continuous from the middle phalanx to the apex of the palmar aponeurosis. Nodule-cord units may occur singly, but a finger tip flexed well into the palm certainly means that there were at least two nodule-cord units. In a few instances there were finger contractures from involuting nodules, but no involvement of the palm. Palmar involvement without finger involvement is relatively common and offers the best opportunity for observing the nodule-cord-unit concept.

If the fibrous cords are reactive (the result of hypertrophy from intermittent mechanical stresses) they should be the largest where they are subjected to the greatest tension stresses; this is precisely what was observed. The fibrous cords grow to large dimensions in those persons who use their hands a great deal. Patients who had unusually large cords frequently were preoccupied with passive stretching of the extensors of the involved fingers; this observation is further evidence that the fascial cords represent functional hypertrophy of a fascial band. At sites where there is little opportunity for either cord formation, or for subject-

FIG. 8-A

A palmar nodule (arrow) nearing the end of the involutional stage. Note the long contiguous cord.

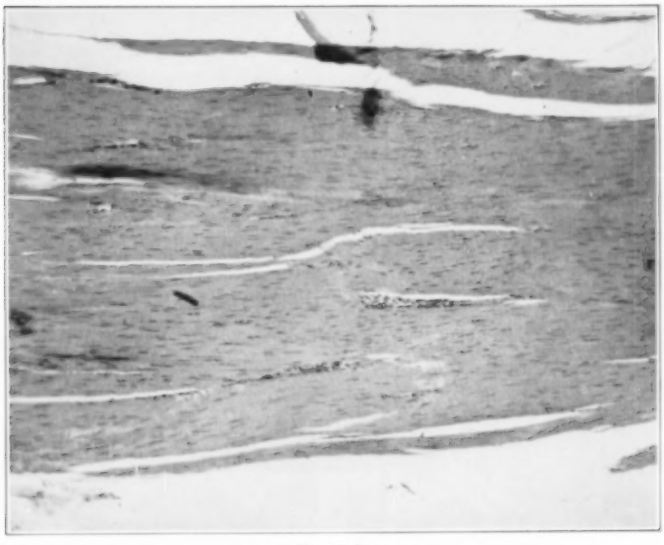


FIG. 8-B

Photomicrograph of a fascial cord.

ing the small cord that does form to the stresses that would cause substantial hypertrophy, there is little cord formation. Such sites are the lateral and medial aspects of the palm, or the fingers. An example is the nodule that occurs lateral to the first, or medial to the fifth, metacarpal head (Fig. 16).

Whether or not a nodule will be capable of causing disabling contractures of a joint clearly depends on the location of the nodule. In general, the more proximal the location, the less potential that nodule will possess for creating a contracture. Conversely, the more distally located the nodule is, the more contracture it can cause—but here there needs to be a qualifying statement. If a nodule is located directly over a joint, it will have a decided mechanical advantage during its involution. A good example is seen when the nodules develop directly over a metacarpophalangeal joint between the transverse creases of the palm. With every millimeter of contraction such a nodule may create several degrees of flexion contracture in the finger. Actually, several nodules were repeatedly measured during involution and, in some instances, the nodule contracted its full longitudinal diameter. A simple experiment can be carried out on a normal palm by pinching the skin between the transverse creases, drawing the creases closer together. If pinching the skin is carried out directly over a metacarpophalangeal joint, it can create anywhere from 40 to 90 degrees of flexion in that joint if the skin

FIG. 9

The hand of a physician, eighty-five years old, at autopsy. The untreated Dupuytren's contracture was of approximately forty years' duration and in the residual stage. Note the tendon-like character of the fascial band (arrow). No trace of the nodules which created the contracture could be found.

FIG. 10

FIG. 11

Fig. 10: The hand on the right shows the proliferative stage. Similar fifth-ray nodules in the hand on the left have completed their involution leaving contractures and residual cord (as marked).

Fig. 11: The hand of a man, thirty-five years old, the only Negro patient in the series. Nodules located this far proximally in the palm cannot cause significant contracture.

is held pinched between the finger tips. By the same token, if a nodule is located directly over the volar aspect of the proximal interphalangeal joint—a frequent location for nodules—that nodule will have, during its contracting phase, tremendous contractural advantage. Here, again, some idea of the manner in which that joint can be contracted to as much as 90 degrees by a very short range of contraction in a nodule can be understood by simply visualizing a nodule steadily decreasing in diameter and drawing all adjacent soft tissue with it. If a nodule occurs at sites where the mechanical situation does not favor the creation of a flexion contracture of either an interphalangeal joint or a metacarpophalangeal joint, then the nodule goes through its life cycle creating relatively little disturbance.

It is not common for nodules to be located in the proximal one-half of the palm, except in the thenar eminence, and when they are so located they cause little difficulty. Nodules in the palm, that lie between metacarpal heads or in the region of the webs, produce cords which take an oblique course and seldom produce contractures (Fig.1). In the same way, nod-

Fig. 12-A: A hand before operation. The large, twin nodules are over the proximal phalanx of the ring finger. Note the heavy cord proximal to the two nodules.

Fig. 12-B: The same hand three weeks postoperatively. Normal mobility was restored. There was no recurrence in a follow-up period of three years.

FIG. 12-A

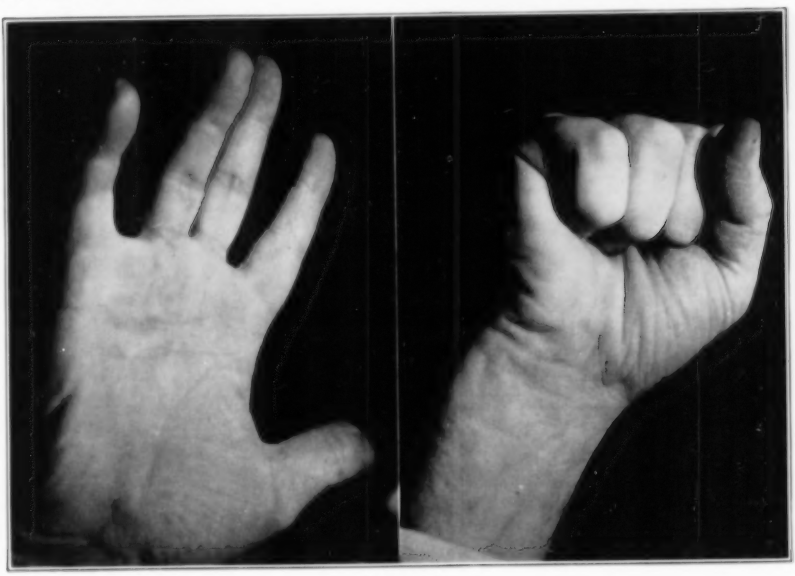


FIG. 12-B

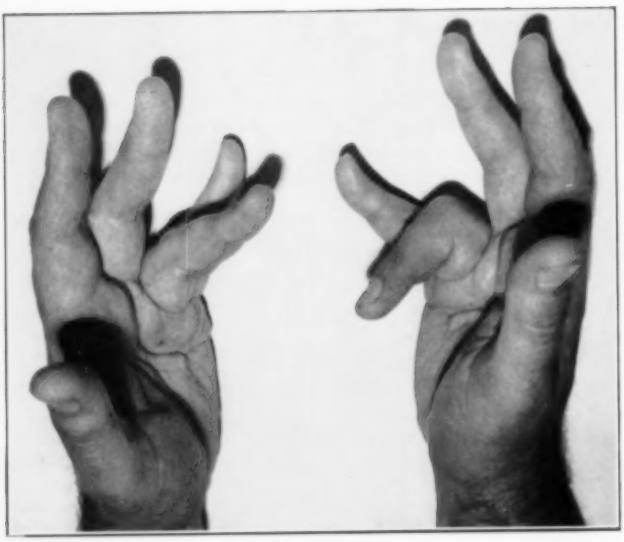


FIG. 13-A

Hands showing the involutional stage. Subcutaneous fasciotomy of the palms and excision of the nodules were performed on both the palms and the involved fingers.

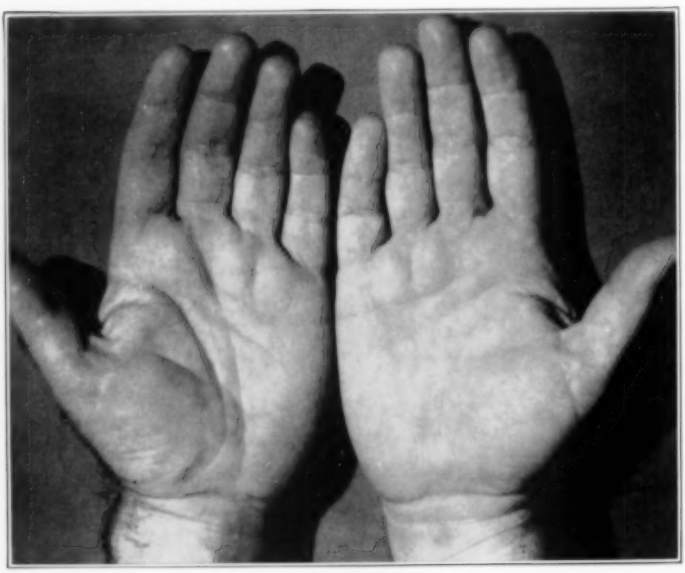


FIG. 13-B

The same hands five years after operation.

ules that are located either on the medial or lateral aspects of the fingers have less capacity to produce flexion contractures, particularly when they lie half-way between the proximal interphalangeal joint and the metacarpophalangeal joint. Contractures at such sites tend to limit or even obliterate spreading of the involved fingers. Many Y-shaped cords are seen and these are the result of eccentrically placed nodules. It is interesting and clinically useful to analyze the pattern of the nodule-cord units that develop in the thenar eminence and the thumb. The most

FIG. 14

FIG. 15

Fig. 14: Hand showing a solitary nodule-cord unit. The nodule at the arrow point was observed over a period of eight years as it involuted and caused the prominent reactive cord extending to the apex of the palmar fascia.

Fig. 15: The two nodules in the hand represent the total involvement. They were excised. Note the V-shaped skin contracture distal to the palmar nodule.

Fig. 16: Hand showing abduction of the little finger. This deformity is the result of involution in a nodule located over the medial aspect of the fifth metacarpophalangeal joint.

FIG. 16

common site for these nodules is over the first metacarpal head. A nodule that forms over the metacarpal head adjacent to the thumb web will form a cord that extends through the web to the second metacarpal head. Cords from nodules over the anterior, lateral, and medial aspects of the first metacarpal head tend to form a radial arrangement of cords beneath and in the skin of the thenar eminence; there may be two or three separate nodule-cord units. A cord that forms in the web of the thumb from a nodule over the medial aspect of the first metacarpal head will tend to be well circumscribed and rounded, whereas the cords that form in the remainder of the thenar eminence tend to be flat with less well defined margins. Nodule-cord units of the thenar eminence can draw the thumb toward the palm and can sharply limit abduction, extension, and opposi-

tion. When a volar nodule forms over the interphalangeal joint of the thumb, the proximal cord of this nodule-cord unit generally joins a nodule-cord unit to the thenar eminence. It is thus possible, with the completion of involution, for a cord to extend from the terminal phalanx of the thumb to the base of the thenar eminence.

Nodules overlying metacarpal heads tend to become anchored securely to flexor-tendon sheaths. There is relatively less tendency for the nodules in the proximal one-half of the palm to develop attachments to tissues deep to the fascia (except tendon sheaths). In other words, nodule fixation in the palm is predominantly between the fascia and the skin and not between the fascia and the deep structures. Hypertrophy of normal bands and septa that penetrate deeply is not uncommon, particularly in the fingers. It has also been observed that deeper aspects of the palmar fascia, particularly the transverse fibers over the metacarpal heads, may appear completely normal in the presence of considerable involvement of the overlying longitudinal fibers. A nodule on the lateral aspect of the proximal third of the ring finger will, in its contracting stage, draw this finger toward the long finger and sharply limit spreading of these two fingers. Likewise, a nodule over the medial aspect of the little finger can create an adduction contracture and the patient may lose all ability to draw the little finger to the ring finger. This is as objectionable, to most patients, as a flexion contracture.

The rate with which the nodule involutes and, therefore, the rate of contraction, is widely variable and does not take place on any definite or predictable time schedule. A nodule can appear in the palm, a finger, or the sole of the foot, and remain unchanged over a period of many months or years, and then within a few months undergo involution and create a contracture dictated by the location and size of the nodule (or nodules). While the nodule tends to slowly involute and contract, there may be a period of a few weeks in which there is rather rapid progression of the contracture. In several instances, nodules remained unchanged for more than twenty years before involuting. While the rate of contracture is unpredictable, one can predict that contracture will nearly always occur at one time or another. Therefore, in analyzing a hand involved in this disease, it is readily possible, after palpating the nodules or nodule-cord units, to estimate the potential further contracture.

As the process of involution progresses, the nodule becomes less and less well defined until at the end of the process the nodule is no longer present and, of course, is no longer palpable. It is important not to misinterpret a rather rounded fold of skin, created by the contracture, as a nodule (Figs. 21-A and 21-B). If contractures at the proximal interphalangeal joint are allowed to remain untreated for long periods of time, irreversible changes may occur, including contractures in the ligamentous apparatus, intra-articular changes, and even fibrous ankylosis (Figs. 18-A, 18-B, and 20). The nodule can extend medially and laterally to the flexor tendons and their sheaths and directly involve the joint capsule. Capsulotomy or partial capsulectomy is indicated in some of these instances, but the results of capsule surgery leave something to be desired. In analyzing the involved hand it is important to evaluate the stage each nodule has reached. New nodules may appear in the palm at widely spaced periods. With this wide variation in time of appearance and the wide variation in rate of involution, it is not surprising that the microscopic picture of the nodular tissues reveals, at different sites, wide variations in both cellular maturity and the proportion of collagen to cells. Writers on this subject [11,20,22] saw no basis in the microscopic picture for reconstructing the pathogenesis of the nodules and cords. Skoog said that it was not possible to establish any relationship between the histological picture and the clinical characteristics of the disease.

In the plantar fascia, the nodules tend to be larger than in the hand, coalescent nodules are more common, and the involutional process tends to be slower.

The hypertrophy of bands of palmar and plantar fascia, which occurs when they are subjected to pronounced intermittent tension stress, is not unlike the

FIG. 17-A

Preoperative appearance of the hands of a general surgeon, sixty-two years old. Subcutaneous fasciotomy was performed in 1948. There was partial recurrence during the first postoperative year. The causative nodules were then removed; there was no further recurrence.

FIG. 17-B

Photograph of hands showing postoperative appearance. The patient resumed operating three days following subcutaneous fasciotomy, and within ten days after excision of the nodules.

dramatic hypertrophy that one sees after transplanting fascia lata grafts to the abdomen extending them from the ribs to the ilium [16] (Lowman's operation). The intermittent tension stresses on these fascial straps are pronounced and the reac-

FIG. 18-A

FIG. 18-B

Fig. 18-A: Photograph of hand showing contracture of the proximal interphalangeal joint of the little finger, in the residual stage.

Fig. 18-B: Photograph of hand showing postoperative appearance. The fibrous cord was excised at the site of the contracture, in addition to capsulotomy of the joint. The result was unsatisfactory. The proximal interphalangeal joint of the little finger is the most difficult problem in Dupuytren's contracture.

tion of the fascia is one of strikingly pronounced hypertrophy (Fig. 23). A thin, flat fascial graft, one or two millimeters thick and one-half inch to one-inch wide, can become as large and thick as the patient's tendo achillis, exhibiting a tendon-like structure of great strength.

THE RESIDUAL STAGE

With complete involution the nodule disappears, leaving only a focus of dense adhesions and the reactive proximal fibrous cord which is almost acellular and tendon-like. Where the nodule existed the skin is fixed, drawn into folds, and securely fused to underlying fascia. The cords may be short, existing only in the palm. If there is only a palmar nodule, usually between or adjacent to transverse creases, the skin will be drawn in a V-shaped contour in the palm just distal to the site where the nodule is anchored to the overlying skin (Fig. 15). Proximal to the contracted focus of skin will be the clearly defined fibrous cord which extends to the apex of the palmar aponeurosis. There is seldom any pathological fixation of the skin to the fascial cords in the proximal half of the palm since nodules are infrequent at this site.

In palpating a cord in which the nodules have entirely disappeared, the diameter of the cord will be found to vary but little from one site to another; thus, the margins are parallel. However, when there is fixation of the cord to the skin or skin callosities, palpation of the cord can be rather difficult. With practice, the presence or absence of nodules can be learned by careful palpation. Where no nodules can be identified, and where the contracture has not recently changed, it can be assumed that the process is completely involuted and that no further contracture will occur. After the process has burned out, areas of uninvolved palmar

fascia adjacent to the cords may atrophy and almost disappear. Likewise, if the finger contracts completely into the palm where further extensory stresses cease, the lack of stress on the cord is ultimately reflected by atrophy of the cord. Instances were encountered where the finger was completely flexed into the palm and the cord was reduced to a narrow, thin band. Such an instance was seen in a physician, eighty-five years old, who had had Dupuytren's contracture for approximately forty years and in whom the little and ring fingers of the right hand, completely flexed into the palm, had been useless for approximately twenty years preceding death. At the death of this physician, permission was granted to dissect the hand and it was found that these fibrous cords, no doubt once strong and thick, had atrophied until they were only thin bands resembling the digital tendons of an infant (Fig. 9).

Irreversible joint changes are much more likely to develop in the proximal interphalangeal than in the metacarpophalangeal joints. Joint involvement may be characterized by capsular contractures which

FIG. 19-A

Hand of a man, eighty-one years old, showing the residual stage.

FIG. 19-B

One month following subcutaneous fasciotomy of the palm and partial excision of the digital cord. The patient had already returned to bowling and playing the zither, his principal pleasures in life.

occur through physiological adaptation to a protracted flexion. Atrophy and degeneration of the articular cartilage may occur together with contractures of the overlying skin. These changes are the result of the positional adaptation, involution of the nodules and, in some instances, actual encroachment on the stratum fibrosum of the joint capsule by the nodular fibroplasia. If the joint remains contracted for long periods of time and, in particular, if there has been a nodule in direct relationship to the joint capsule, it may not be possible to correct this contracture completely, even though the procedure would include capsulotomy or partial capsulectomy. Adaptive shortening of the digital nerves, vessels, and tendons occurs and must be taken into consideration in surgically correcting the contractures. The digital nerves and vessels lie alongside the flexor tendons and rarely depart from this position.

Fig. 20-A

Fig. 20-A: The little finger had been contracted completely into the palm for twelve years. Irreversible changes in and around the proximal interphalangeal joint were treated by resection of the distal one-third of the proximal phalanx and fusion of the joint in 30 degrees of flexion. The result obtained is usually preferable to amputation for most patients.

Fig. 20-B: End result after resection of the distal portion of the proximal phalanx of the small finger and fusion of the proximal interphalangeal joint

Fig. 20-B

FIG. 21-A

FIG. 21-B

Fig. 21-A: This hand, showing residual palmar involvement from a solitary nodule, was treated by subcutaneous fasciotomy.

Figure 21-B: There was no recurrence during the seven-year follow-up period.

While the hypertrophied fascia may bowstring volarward, the nerves and vessels are rarely carried forward with the fibrous cords. However, it is not uncommon for the nerves and vessels to become intimately entrapped during growth of the nodules. This is much more likely to evolve when a digital nodule arises in an eccentric position to lie medially or laterally rather than directly volarward in the mid-line. In the palm, even with extensive involvement, the nerves and vessels remain in their normal position and are neither enveloped nor encroached upon by the nodular masses.

THERAPY

When the contracture warrants treatment, the definitive treatment is surgical. Notwithstanding this well established fact, numerous non-operative methods have been employed and enthusiastic claims have been made of their efficacy in resolving both the disease process and the flexion contractures. Non-operative therapy includes a variety of splints, ultrasonics and other physical therapy modalities [22], roentgen therapy [8,9], vitamin E [14,21,23] and corticosteroids of which cortisone and hydrocortisone are the most frequently suggested. In the natural history of the Dupuytren process as here portrayed, the nodules undergo involution which generally creates contractures. In the past, little attempt has been made to classify the stage of the disease and then employ therapeutic methods based upon the predominant stage of the process. Obviously, if the process has burned out, leaving only the dense, almost avascular, tendon-like cords as a permanent residue, it is not to be expected that vitamins, hormones, roentgen therapy, splints, and various types of physical therapy would have any significant influence. It is hoped that in the future, an attempt will be made to limit non-operative methods to cases in which the disease is still active and the nodules are in either the proliferative or early involutional stage. As a facet of clinical management in this series, hydrocortisone acetate was injected into nodules on numerous occasions. The results to date have been disappointing, with the exception of several early-stage nodules which were rather soft and were actively growing. A definite statement on the value of this method cannot be included in this report. The ideal form of therapy would be a method that could be employed with the first appearance of the nodules that would cause a prompt resolution of the nodules without the nodule undergoing contracture. The use of hydrocortisone acetate, injected into the nodule, roentgen therapy, or ultrasonic therapy is limited to carefully selected early cases.

SURGICAL THERAPY

Since surgery has offered us the only reliable method in the management of this condition, intensive investigation has been directed toward surgical techniques. I have developed a method of surgical management of Dupuytren's contracture which is based upon my concept of the pathogenesis of this disease. If it be true that the nodule is the essential lesion, and my studies indicate that it is, it is not necessary to do a radical excision of all of the palmar fascia and associated fibrous cords. To eradicate the aggressive factor, it is necessary only to completely excise the nodules. If the process is in a stage of nodule-cord units (involutional stage), operative procedures which do not include excision of the nodules,

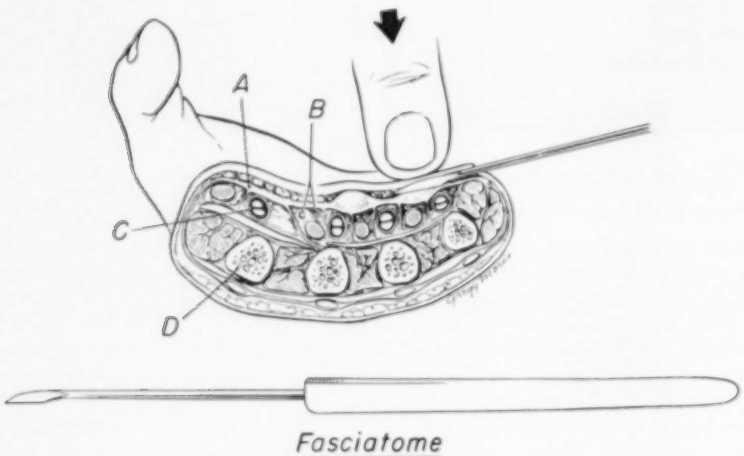


FIG. 22

Schematic drawing: the triangular handle of the fasciatome helps to indicate the location of the sharp edge of the blade when it is under the skin.

The cross-section drawing shows: *A*, the palmar aponeurosis; *B*, the neurovascular bundle; *C*, the flexor tendons; and *D*, the second metacarpal.

for example, subcutaneous fasciotomy, will generally be followed by at least a partial recurrence of the contracture. On the other hand, if the nodules are completely excised, and the fibrous cords are sectioned subcutaneously or by direct vision, recurrence will not take place unless there is some subsequent development of new nodules. In the involutional stage, excision of the nodule is the most essential step in the operative procedure. If the technique of subcutaneous fasciotomy is not familiar to the surgeon, the proximal cords frequently can be left undisturbed although the skin should be undermined at the sites of skin fixation or contracture. Undermining the skin can be accomplished by the same skin incision used to excise the nodule, by undermining proximally or distally with a small blade. When palmar nodules have completed their involution, leaving only residual fibrous cords and contractures, it is necessary only to section these fibrous cords subcutaneously at multiple levels and undermine the skin wherever it is pathologically adherent. In this residual stage, subcutaneous fasciotomy well deserves a prominent place in therapy.

Under no circumstance should subcutaneous fasciotomy be considered lightly or casually and interpreted as an easy procedure. It is a safe and effective procedure where proper attention has been given to mastering the important details of the technique. As much precision and skill are required as with the open operation. To me, radical excision of the palmar aponeurosis has appeared to be unnecessary.

Indications for Subcutaneous Fasciotomy

1. Subcutaneous fasciotomy should be restricted to the palm, proximal to the webs of the fingers and distal to the apex of the palmar fascia (junction of the thenar and hypothenar eminences).

2. Subcutaneous fasciotomy is applicable in all cases of palmar involvement where the nodules have either partially or totally involuted. Actually, this represents the majority of the surgical cases. In the involutional and residual stages of palmar nodules, there are fascial cords proximal to the nodules. These cords can be well resolved by subcutaneous fasciotomy.

Contra-Indications for Subcutaneous Fasciotomy

1. Subcutaneous fasciotomy should not be employed in fingers or thumb (or in the webs of the fingers).

2. Subcutaneous fasciotomy is unnecessary when the nodules of the palm are

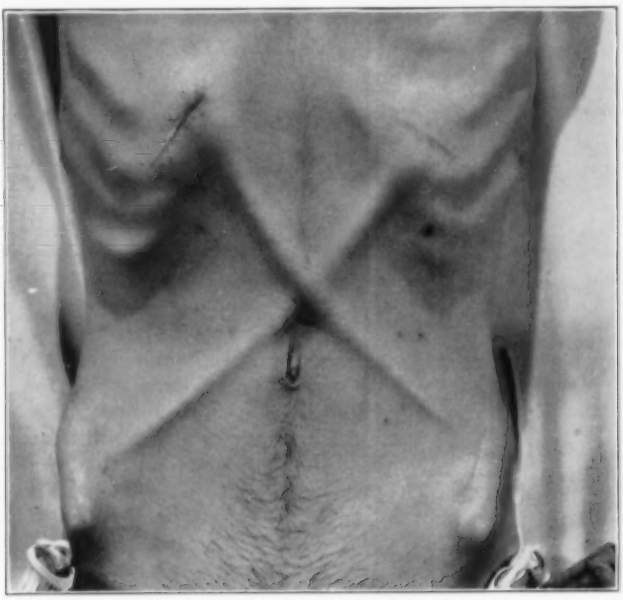


FIG. 23

Criss-cross fascial straps (patient's own fascia lata) have been extended from the rib margins above to the iliac crest below (Lowman operation) for flaccid paralysis of the abdominal wall. Intermittent tension stresses on these thin straps lead them to hypertrophy into thick fibrous cords. This same mechanism, in my opinion, is the cause of the cords in Dupuytren's contracture. (Illustration courtesy of Dr. C. L. Lowman.)

in the proliferative stage. (In this stage the hypertrophied fascial bands have not yet made their appearance.)

3. Subcutaneous sectioning in the palm should not be carried out if there is any question about the diagnosis. The prominent flexor tendons of rheumatoid arthritis and senility must not be mistaken for fascial cords.

Palmar Involvement versus Digital Involvement

In the vast literature on Dupuytren's contracture, the palm has been the center of discussion. In reality it is not the palmar lesions that create the greatest contracture and disability; rather, it is the nodules in relation to the proximal interphalangeal joints. No amount of palmar dissection, no matter how radical, will

resolve contractures of the proximal interphalangeal joints. This site of involvement must be approached directly, since it is not possible for palmar lesions, that is, palmar nodules, to create contractures of the interphalangeal joints. These joints are contracted by the involution of nodules that form directly over, or in close approximation to, them. Therefore, involvement of the proximal interphalangeal joint must be dealt with by surgery directly at the site of an existing causative nodule or its contracted residue. Prior to operative therapy, the hand must be meticulously studied; every nodule and every cord must be clearly delineated in the surgeon's mind as he plans the surgical correction. Identifying the stage of the disease leads to an estimate of the status of the contracture. The plan of therapy is not complex if this information is utilized; results from pursuing this method of analysis and management have been gratifying.

FIG. 24

This burn scar on the long finger was of many years' duration. A cord of hypertrophied palmar fascia extended from the base of the finger to the apex of the palmar fascia. Extensory tugging on the band of fascia caused the hypertrophy, just as it does in Dupuytren's contracture.

Subcutaneous Fasciotomy

Sir Astley Cooper was the first to use subcutaneous fasciotomy in what must have been a Dupuytren contracture. Prior to the time of Cooper and Dupuytren, the treatment of Dupuytren's contracture consisted in division of the flexor tendons; the results must have been discouraging. Dupuytren, in 1832, recommended the use of multiple, transverse incisions through the skin and the underlying fibrous cords. The small skin incisions were left open. A variety of limited operative procedures were recommended in the decades that followed. Adams, in 1878, did much to popularize the method of subcutaneous fasciotomy. Good results were claimed by Adams and it was his belief that there never would be more than a partial recurrence. He stated that all operations by open wound should be condemned as unnecessarily severe. Macready, a student of Adams, continued the use of subcutaneous fasciotomy and, in 1890, stated: "The subcutaneous treatment of Dupuytren's contracture of the palmar fascia is so successful with those who use the necessary observances, that it is hard to understand why the treatment by open wound still holds its ground." Keen, at the turn of the century, did much to popularize radical excision of the palmar aponeurosis as a routine method irrespective of the extent of the pathological process. Since the turn of the century, aponeurosectomy has steadily increased in popularity and has become almost universally adopted as the method of choice [2,4,5,12,15,19,20,22]. For the most part it is carried out without regard for the extent of the disease or the stage of the process. Hamlin, in limiting the excision to involved areas observed, in fourteen patients, a sharp decrease in the time between operation and return to work. He emphasized the necessity of removing all diseased fascia and stated that the cords and the fasciculi to the deep fascia must be searched for and excised. In thirty cases of radical excision that were reviewed, the average time between

FIG. 25

Typical knuckle-pads. These dorsal nodules overlie the extensory apparatus of the proximal interphalangeal joint. Contractures of these nodules have not been observed.

operation and return to work was 118 days. In the fourteen cases of limited excision, the average was twenty-one days, notwithstanding longitudinal palmar incisions and dissection of the cords to the apex of the palmar fascia.

Less radical therapy, particularly treatment by subcutaneous fasciotomy, has been mentioned only rarely since the turn of the century, and usually mentioned only to condemn it. In his comprehensive monograph, Skoog summed up the literature on subcutaneous fasciotomy and ended his summary by condemning the method. Bunnell used subcutaneous fasciotomy in severe cases preliminary to radical excision of the aponeurosis. He stated that the radical operation should be performed within three weeks after the subcutaneous release to prevent loss of the correction achieved by the subcutaneous fasciotomy.

On the basis of my studies, it is evident that subcutaneous fasciotomy used alone and routinely without regard for the stage of the disease will be followed by a high incidence of recurrence of the disease. If the surgeon is working principally with elderly patients, as appears to have been the case with Adams and Macready, the incidence of recurrence would be low because a high percentage of these patients would have a long-standing and completely involuted process; conversely, those working with younger patients would have discouraging experience with routine use of subcutaneous fasciotomy. In the series of fifty cases reported by Skoog, all but five patients were under the age of fifty, and thirty-six of these patients were under forty.

Two erroneous concepts are widely encountered:

1. With the appearance of a nodule in the palm, it is a foregone conclusion that there will be more nodules at a later date and that the patient, without radical therapy, is destined to a gradual progression of the disease, ending inexorably with the fingers contracted into the palm. In the experience with the large series of cases herein reported, this error has become clearly defined. A patient with active involvement stands a better than even chance of never having an extension of the process to other areas.

2. It is widely believed that if the radical operation is carried out, the patient can be assured that there will be no further recurrence or extension of the

process. This is viewed as erroneous on the basis of several well documented cases where new nodules have appeared in hands after meticulous and complete excision of the palmar aponeurosis. It is my recommendation that only that portion of the palm and the fingers actually showing nodules should be the site of open surgery. In this study the evidence indicates that radical dissection of uninvolved areas of the palm or fingers has little to support it.

TECHNIQUE OF SUBCUTANEOUS FASCIOTOMY

Subcutaneous fasciotomy consists in severing palmar fascia subcutaneously at multiple levels. This technique is limited to the sectioning of well defined, fibrous cords. The procedure is carried out with a small knife, which will be referred to as a fasciatome. The writer's fasciatome has a triangular-shaped handle so that the location of the cutting edge of the small blade, when it is beneath the skin, will always be known to the surgeon (Fig. 22). The fibrous cords are sectioned transversely, the first level being just distal to the apex of the palmar fascia as it lies between the thenar and hypothenar eminences. The next level is at the site of the proximal transverse palmar crease, and the third, and final, level in the palm is at the level of the distal transverse crease. Through a one-eighth of an inch puncture wound, made by a pointed scalpel in the skin lines along the medial border of the palm, the fasciatome is inserted with the blade in a transverse position just beneath the skin. The blade is passed into the subcutaneous tissue directly beneath the skin until it reaches the site of the cord or fascia to be divided. The blade is turned until the sharp edge lies against the superficial surface of the cord to be divided (Fig. 22). With the surgeon's finger tip placed on the skin that overlies the back of the blade, the blade then is pressed by the surgeon's finger tip through the fibrous cord. These cords offer considerable resistance and it is almost a gritty sensation that the blade transmits to the surgeon's fingers as the blade passes through the fascial cord. Solid resistance to further progress of the blade ceases when the cord has been divided, and it is then as though the blade were pressing against sponge rubber. The blade is now advanced between the skin and the cord and another one-sixteenth or one-eighth of an inch of the cord is divided. Each time the blade is advanced between the skin and the involved area of the fascia, the blade is turned 90 degrees so that it is flat. The blade is turned again so that the cutting edge can be pressed through the cord or fascia. Under no circumstances should a reciprocal stroke be employed since this would obviously endanger the underlying nerves, vessels, and tendons. If no sawing or reciprocal action is employed, the vessels, nerves, and tendons are not in danger. Where there are adhesions between the skin, nodules, and fibrous cords (and this is regularly encountered) the overlying skin is dissected off the involved focus of fascia by turning the blade to a right angle and undermining the skin. Care must be taken, in this part of the procedure, that the blade does not repeatedly penetrate the skin; however, no harm is done if the point of the blade should once or twice protrude through the skin. Frequently, during the undermining, the skin is so thin that the outline of the blade can be seen. Where there is a deep crease at sites of considerable flexion contracture, the bottom of the crease, or dimple, may be difficult to see; it is best in this situation to divide the cord before undermining the skin. If an attempt is made to undermine the skin first, it is difficult to prevent severing the apex of the deep dimple, or crease. Once the cord is divided the apex of the dimple can be seen, as can the apex of a deep crease. Pathological fixation of the skin is a prominent part of this disease and a major source of the contractures. The skin can be undermined as extensively as desired without fear of necrosis. There were no instances of skin necrosis regardless of the extent of the undermining and the thinness of the skin where no incision was made in the palm.

Under no circumstances should the blade be plunged into the palm and the cutting edge turned toward the surface so that the cord and fascia are divided in

a cut carried toward the skin. This would grievously endanger the deep structures. The blade should not be passed into the webs of the fingers since the nerves and vessels become fairly superficial at this point. It is reasonably safe to use the subcutaneous technique in the fingers proper if the fibrous cord is tented up and not displaced from the mid-line. In numerous instances the nodule responsible for the cord develops toward the lateral or medial aspects of the finger. Because of the danger to digital nerves and vessels, a longitudinal incision should be made over the mid-lateral or mid-medial aspects of the finger at the site of the cord. The nerves and vessels should be visualized by meticulous dissection, retracted, and then the cord should be divided. A segment of the cord should generally be removed and, when present, the nodule or nodules. When large nodules are present, both a mid-lateral and a mid-medial approach may be necessary. The nerves and vessels should be exposed proximal or distal to any nodule encountered and followed along the nodule.

Involuting Palmar Nodules

After subcutaneously sectioning palmar cords, a short transverse incision is made in either the distal or the proximal transverse palmar crease and the nodule, or nodules, removed. The skin incision is not usually long—seldom more than one and one-fourth inches—and through this approach the nodules are carefully visualized and excised along with the adjacent portions of their respective cords. The dissection is carried out proximodistally, the proximal fibrous cords having been previously divided by subcutaneous fasciotomy. The ends of the cords that were divided subcutaneously are found not far from the nodules and are readily brought into the operative field. The tendons, nerves, and vessels should then be identified. Where the nodule is securely anchored to the underlying tendon sheath, the sheath at this site should be excised along with the nodule. A thenar-eminence nodule over the first metacarpal head is usually best visualized by a transverse skin incision in the transverse crease overlying the first metacarpal head. The fibrous cords that extend from this nodule into the thenar eminence can be divided subcutaneously. It has been claimed that subcutaneous fasciotomy could not possibly succeed because there are no means whereby the deep ramifications of the fascia can be divided. This is an erroneous concept. In the cases of this report, complete correction of palmar contractures nearly always occurred when the cords were divided and the skin undermined at sites of adhesions. This experience indicates that the deep ramifications of the fascia are not nearly so important in the cause of the contractures as has been supposed.

Skin Closure and Postoperative Care

Skin incisions are accurately but loosely closed by interrupted everting sutures and the procedure is completed by the application of a compression dressing generally consisting of fluffed-gauze sponges and a two-inch elastic bandage. If the skin of the palm is contracted, and if extending the fingers would place a strain on the skin incision, the fingers are held flexed by adhesive-tape loops in the amount of flexion that brings relaxation of the skin incision; this is maintained until the skin is healed. After the wound is healed, vigorous exercises are begun and, in most cases, the skin can be relied upon to stretch to the length required. It is remarkable how well the skin is able to return to a more normal character. In my opinion, there is no evidence that areas of involved skin should be excised and replaced by skin grafts; this procedure was never performed on any patient in the series herein reported. When subcutaneous fasciotomy has been used alone, the patient was able to begin actively using his hands within two to seven days. In several instances, the patient was able to return to manual work within one week. In most instances, no splints of any type were employed. In a few of the more resistant contractures, a night splint was used. In three patients, a stellate block was employed for postoperative pain and tenderness and evidence

of sympathetic-nervous-system disturbance (reflex sympathetic dystrophy). Hydrocortisone acetate was injected when the postoperative swelling and pain were beyond average. Both the stellate blocks and the injections of hydrocortisone proved helpful enough to justify their use.

Postoperatively, in palpating areas of palmar subcutaneous fasciotomy, the fibrous cords that previously were so conspicuous were no longer palpable. These sectioned cords presumably atrophy and disappear once the stresses, which the writer believes created and perpetuated them, have no further influence. When the related nodules were properly removed and the cords completely divided, the cords gradually disappeared and were not a source of recurrence. In the residual stage, where only the subcutaneous technique is employed, recurrence generally means that the cords were not completely divided.

In instances where there is an extreme contracture (90+ degrees) in the proximal interphalangeal joint, in which the contracted soft tissues (tendons, ligaments, nerves, and vessels) will not allow the finger to extend, the distal one-third of the proximal phalanx can be excised and the joint fused in 30 degrees of flexion. (A small Kirschner wire is used longitudinally for fixation.) This will give a shortened finger but most patients will prefer it to either amputation or extreme contracture. This technique has been used on the little finger in two instances with good results.

ANAESTHESIA

The anaesthesia most frequently employed in this series was local infiltration of either 1 per cent procaine hydrochloride or 1 per cent xylocaine. A 25 or 27-gauge hypodermic needle is used for the first infiltration (five to ten cubic centimeters) into the lateral border of the proximal one-third of the palm. A 22 or 23-gauge spinal needle is then used, and the xylocaine solution infiltrated subcutaneously throughout the palmar operative sites. The needle is inserted at two levels in the palm: the proximal third and the distal third. This technique produces excellent and dependable anaesthesia in the palm and all fingers. Separate infiltration is required at the base of the thumb and in the thenar eminence if surgery is to be performed at these sites. A sphygmomanometer cuff or pneumatic tourniquet is employed around the mid-forearm. This tourniquet was exceedingly well tolerated for as long as forty-five minutes—well within the time customarily used for this operation. In the instances where the operation had not yet been completed, the tourniquet was released for a few minutes and either reapplied or the remainder of the operation completed without it. Nearly all of the patients in this series were out-patients and were operated upon with only a barbiturate as the preoperative medication.

POSTOPERATIVE COMPLICATIONS

Complications have been few and, with two exceptions, were not serious. No severe infections developed. In the two instances of postoperative infection—the only instances where antibiotics were given—the infection was of low grade and of only a few days' duration.

Hematomata were a factor in impaired skin circulation at the operative site in four instances; in these a small focus of skin necrosis developed. Skin grafts were not needed. In only one instance did a large hematoma develop following extensive subcutaneous palmar fasciotomy. In this hand the skin was tented up and paper thin at several sites, but no necrosis of the skin resulted. There was not a single instance of skin necrosis from palmar subcutaneous fasciotomy when it was not associated with a skin incision. Skin incisions should be closed with sufficient space between the interrupted sutures to permit blood to find an exit.

The most feared and disabling complication is reflex sympathetic dystrophy. Fortunately it is rare, having occurred in only three instances of the 154 reported cases. In these three patients pain—generally of a burning character—stiffness,

reddish discoloration, and swelling of the fingers and wrist persisted for five to eighteen months. The pain and stiffness were severe in the shoulder and hand, but for the most part the elbow was spared. This is a distressing complication for both patient and doctor. Only one of these three patients regained full motion in the involved joints.

Hypalgesia

Impaired sensation in the form of hypalgesia occurred in eight instances. The cause was either division of a digital nerve during the operation or stretching a digital nerve (stretch neuritis) when the proximal interphalangeal joint was straightened after a protracted severe flexion contracture. In eight instances, the nerve was sufficiently injured to cause hypalgesia. In three hands there was recovery of normal sensation within a few weeks; in the other five the hypalgesia still persisted at the time of writing. For the most part the hypalgesia was well tolerated and caused the patient little concern.

In nearly all instances the digital nerves are more likely to be injured within the finger than in the palm. Palmar subcutaneous fasciotomy, when properly done, does not endanger the nerves, blood vessels, or tendons. The subcutaneous technique within the fingers is not recommended because of the danger of dividing a digital nerve. When there are large, eccentrically placed nodules in a finger they may be fused to a digital nerve. Even with direct vision it takes meticulous technique to prevent injury to the nerve. The nerves and vessels should be visualized proximal to the sites of encroachment and then dissected free.

Pain and itching: Disabling pain and itching occurred postoperatively in eight instances, but resolved in from two to ten weeks. In all the patients the stage of the disease was proliferative or early involutional. Local injections of hydrocortisone at sites of symptoms proved helpful.

Recurrent contracture: Contractures recurred after having been corrected at operation in thirty-one hands. These recurrences were the result, principally, from irreversible capsular changes associated with protracted and severe flexion contractures, impaired extensor function, failure to divide completely the fibrous cords, and inadequate excision of the nodules. Flexion contractures of the proximal interphalangeal joint are the most difficult to correct and have the greatest propensity for recurrence, particularly in the little finger, while contractures of the metacarpophalangeal joint are much more tractable. Involvement of the proximal interphalangeal joint is difficult to treat since the capsular changes may be irreversible, particularly when nodules have involved the capsule.

When flexion contracture is long-standing the extensor apparatus may be impaired. The resulting muscle imbalance can be a factor in creating recurrent flexion contractures.

In nineteen hands (12.3 per cent), new nodules subsequently appeared in other fingers or in the palmar area, clearly separated from the site of surgery. This is not viewed as a surgical complication, but as a potential capacity of the natural process of the disease.

RESULTS

In presenting the results of the operative techniques used in this series, the cases will be divided into three groups according to the predominant stage of the disease existing at the time of the operation: proliferative, involutional, and residual. The majority of the operations were carried out when the disease was in the involutional stage—the one at which the patient usually requests treatment. Another factor accounting for the small number of cases treated in the proliferative stage has been the tendency to postpone surgery during this stage, except in those cases where a nodule directly overlies a proximal interphalangeal joint. Since there are no contractures in the proliferative stage there is seldom disability, although there may be pain and tenderness at the sites of the nodules.

Postoperative results are classified into three groups: good, fair, and poor. In the proliferative stage a good result is one in which there is no recurrence of a nodule in an operative area and no impairment of function. In the involutional and residual stages a good result is a painless hand that is nearly normal in mobility, strength, and appearance. The classification of fair is given to a hand whose function has been substantially improved and in which the contractures have been corrected to at least 50 per cent. In the proliferative stage a slight nodular recurrence is also classed as a fair result. A result is classed as poor in a hand in which the contractures have been improved less than 50 per cent, or there is permanent stiffness. After surgery in the proliferative stage an obvious recurrence of nodules at a site of surgery is classed as a poor result. (A second operation was generally followed by a good result.)

Proliferative Stage

Twelve patients were treated by nodular excision. All had unilateral involvement and none had contractures. The results, as shown after two to ten years of observation, were: good in seven, fair in three, and poor in two. In the three patients who had fair results, there was a slight nodular recurrence at the site of surgery, necessitating further surgery, in one instance with a good final result. In the two patients who had poor results the nodule (or nodules) recurred. The result of a second operation was good in both cases. Nodules in the proliferative stage have the highest propensity for recurrence, and meticulous technique must be used when nodules are excised during this stage. Nonetheless if a nodule is located over, or adjacent to, the volar aspect of a proximal interphalangeal joint it is proper to remove the nodule even if recurrence is a threat. It is a brief and simple matter to remove a nodule from a hand locally anaesthetized; the patient experiences little incapacity. Even when it must be done a second time, it is far superior to the alternative of permitting the proximal interphalangeal joint to go into a severe flexion contracture with its disturbing incidence of irreversible periarticular and articular changes. Nodules at those sites where there is less potential of contracture can be observed.

Involutional Stage

The contractures in this stage were treated by a combination of palmar subcutaneous fasciotomy and excision of nodules in the palm or fingers or both. The results in ninety-seven patients and 125 hands, as shown after two to ten years of follow-up, were: good in ninety-two (73.6 per cent), fair in twenty-seven (21.6 per cent), and poor in six (4.8 per cent). The fair and poor results were generally caused by irreversible joint changes and recurrent nodules. More meticulous excision of these finger nodules would have led to better end results in the fair and poor groups. This was indicated by the improved result after a second operation on two hands with poor results and nine with fair results. The ultimate results in the 125 hands were: good in 101 (80.8 per cent), fair in nineteen (15.2 per cent), and poor in five (4 per cent).

Subcutaneous Fasciotomy in Involutional Stage

In fifteen patients (twenty-one hands) subcutaneous fasciotomy alone was carried out in the involutional stage as a definitive procedure. Most of these patients were treated early in the study, and the results in these have firmly established that if nodules are left behind at the contracture-producing sites, they will generally cause partial or complete recurrence of the contracture. In these hands the results were: good in five, fair in seven, and poor in nine. In three of the five patients who had good results, the nodules were well advanced in their involution at the time of removal, while in the other two the nodules, although well defined preoperatively, seemed to have been destroyed by the operative procedure. In the seven patients who had fair results there were partial recurrences of

the contractures. The nine poor results could be attributed to leaving behind large nodules in close proximity to the proximal interphalangeal and metacarpophalangeal joints.

Residual Stage

Subcutaneous fasciotomy of the palm, in addition to sectioning of digital fibrous cords through small mid-lateral incisions, was carried out on thirty patients (forty-eight hands). The results, shown after two to ten years of observation, were: good in thirty-seven, fair in six, and poor in five. Many of the patients in this group were old or chronically ill, and this simple operation performed with the hand locally anaesthetized was welcomed by both the patient and his doctor. The fair and poor results were caused principally by irreversible soft-tissue changes although osteo-arthritis also played a part.

RESULTS IN THE TOTAL SERIES

After the initial operation and the revisions, the follow-up studies disclosed that in the entire group of 206 hands the results were: good in 164 (79.6 per cent), fair in twenty-nine (14.1 per cent), and poor in thirteen (6.3 per cent). All were followed for from two to ten years and, in a few instances, twelve years.

SUMMARY

1. A new concept of the pathogenesis of Dupuytren's contracture has been presented together with a plan of therapy based upon this concept. In the disease process three stages can be identified: the proliferative stage; the involutional (contracting) stage; and the residual stage.

2. In a hand with nodules in the proliferative or involutional stage, the sites and approximate degree of potential future flexion contractures can be predicted.

3. Operations, based upon the stage of the pathological process, were carried out, during a ten-year period, on 206 hands of 154 patients. The over-all results were: good in 164 (79.6 per cent), fair in twenty-nine (14.1 per cent), and poor in thirteen (6.3 per cent).

4. Selection and evaluation of therapeutic measures in Dupuytren's contracture should be based upon the stage of the disease existing at the time of the therapy.

5. The nodule is interpreted as the essential lesion; the fibrous cords are interpreted as hypertrophy of fascial bands reacting to intermittent tension stresses. Nodules require excision; the cords do not.

6. In the palm, the reactive fascial cords were sectioned by subcutaneous fasciotomy. In the fingers, the cords were sectioned (or a segment excised) by direct vision.

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DISCUSSION

Primary Tendon Repairs

(Continued from page 598)

these distal joints and boutonnière deformity give us the most difficulty. In the latter we have used Fowler's method of tendon-grafting with improved function.

In flexor tendons we have not used the sublimis tendon of the index or long finger for the flexor pollicis longus but we have relied more on tendon grafts taken from the extensor tendons of the toes. Our grafts in the thumb extend from the distal phalanx to the thenar eminence.

It is refreshing to see that more and more delayed procedures are carried out in the lacerations in the flexor tendons of the fingers. In this series 107 tendon repairs were done as secondary operations. Repair of open fractures, crush injuries, saw injuries, and so forth, should be delayed.

We have just about given up the use of penicillin in our practice, not only because of the danger of anaphylactic reaction as mentioned here but also because of delayed allergic response. We do not use antibiotics routinely on our elective cases. In our acute injuries we use one of the broad-spectrum antibiotics.

I agree with Dr. Kelly that the primary repair of the flexor tendon in the sheath should be done only by interested surgeons. Many times this means that the resident just closes the skin or else the hand surgeon has to get up out of bed in the middle of the night and do the repair himself.

Reconstructive Arterial Surgery in Upper-Extremity Injuries*†

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The abundant collateral circulation in the hand and arm allows simple interruption of major arteries in the upper extremity without amputation in the majority of instances. Unfortunately, this has led to an attitude of careless unconcern on the part of surgeons regarding efforts to re-establish interrupted arterial continuity in the arm. There remains, however, a significant number of patients who suffer either loss of the extremity or crippling disability as a result of interruption of such a vessel. The amputation rate is most disturbingly high in injured patients in whom associated injury to the ischaemic distal portion of the extremity may raise the circulatory requirement for limb survival. In a study of arterial injuries during World War II [2], DeBakey and Simeone found that interruption of the brachial artery above its bifurcation was followed by loss of the extremity in one quarter of cases, while, if this artery was divided above the origin of the deep brachial artery, loss of the limb occurred in as many as 55 per cent of the patients. The amputation rate was 39 per cent when both radial and ulnar arteries were divided; even interruption of the radial artery alone was associated with a limb loss of 5 per cent. These statistics do not reveal the incidence of disability due to poor wound healing and lowered resistance to infection in the surviving hands. Since the vessels above the wrist are of sufficient size to lend themselves to reconstructive surgical techniques, active effort to restore interrupted arterial continuity in the arm is justified. The validity of this statement is amply confirmed by comparison of the World War II figures with those of Jahnke and Seeley in a report [3] of seventy-seven consecutive acute vascular injuries treated in accordance with a reconstructive philosophy during the Korean War. Of twenty-eight major artery injuries in the arm above the brachial bifurcation, twenty-five were treated by primary repair. There were no amputations in this group of arm injuries.

In this paper the general surgical principles and important technical considerations in the treatment of peacetime trauma to the upper extremity with injury to major vessels are discussed and two illustrative cases are reported.

Operative restoration of continuity should be seriously considered in all traumatic interruptions of the major arteries above the wrist. It must be remembered that interruption of the continuity of a major vessel is not necessarily attended by hemorrhage since it may occur as a result of contusion or stretching of the vessel. Such injuries should be searched for by careful assay of the peripheral circulation in the initial examination of all upper-extremity injuries.

The need for major vessel repair is particularly urgent in the presence of associated injuries to the hand since even mild ischaemia impairs wound healing. Under these circumstances simple ligature of a major vessel can be done with confidence only with an isolated injury to the ulnar artery. Certainly in injuries proximal to the brachial bifurcation, or to both the radial and the ulnar arteries, surgical repair of the vessels should be performed on the basis of the statistics previously referred to.

To be successful such surgery must be performed with technical competence

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FIG. 1

"Pigtail probe" for removing adherent clot from small vessels.

that comes only from experience. There is a strong impression among surgeons who have dealt with these injuries that a thrombosed anastomosis may be worse than a ligated vessel because of the likelihood of the thrombus propagating and causing additional interruption of collateral branches in an unsuccessful anastomosis. This type of vascular surgery should not be attempted by the inexperienced surgeon, except under exceptional circumstances. It is worthy of note that the technical skill necessary for small-vessel anastomosis can be readily acquired from work with animals.

In the emergency treatment of open injuries to the major vessels of the upper extremity clamping of the vessel with a hemostat should be avoided. The use of the tourniquet or direct pressure, until the patient is brought to the operating room, will avoid the loss of vessel length necessitated by the application of hemostats and ligatures.

Operative exposure must be adequate. No obligation should be felt to perform this surgery through the initial wound. Extension of the wound or separate conventional incisions for exposure of the vessel should be made without hesitation, as should separate exposures along the distal arterial tree for the removal of thrombus. It is particularly absurd to follow an axillary artery up through axillary fat, when this vessel can be easily exposed through the deltopectoral groove by dividing the pectoralis minor tendon.

A good distal arterial outflow is essential to the success of any major arterial repair. Distal obstruction in the arterial tree will result in sluggish flow through the repaired segment and thrombosis. Additional defects in the vessel distal to the point of obvious injury must, of course, be recognized and repaired, but the most common obstruction to flow is distal thrombosis. The incidence and extent of distal thrombus will increase with the severity of the ischaemia (the sluggishness of the distal flow) and with the delay between injury and operation. When this interval is less than six hours, the distal thrombus is rarely extensive and it can usually be easily extracted through the site of primary injury. From twelve to twenty-four hours after injury the distal thrombus is likely to be extensive especially when there is severe ischaemia. However, at this stage it is confined to the major vessels and is non-adherent. After twenty-four hours it usually is adherent and will be difficult to extract. However, we have encountered a case of axillary embolism as late as six days following occlusion, in which it was possible to extract the distal thrombus from the radial and brachial artery successfully so that actively pulsating vessels in the hand were observed several days later, at the time of amputation. Amputation was necessitated by extensive necrosis of skin and forearm muscles resulting from the extended period of severe ischaemia before surgery.

If the distal thrombus, which has been withdrawn or milked from the vessel at the site of injury, has a blunt end and if back bleeding appears, one can be reasonably sure that the distal thrombus has been completely removed. Otherwise further efforts at distal thrombectomy are in order.

The passage of catheters down the artery from the point of primary obstruction is rarely rewarding and tends to ram clot further down the vessel. The open artery distal to the thrombosed segment must be located and exposed. The clot can then be removed in a retrograde fashion by flushing or by use of instruments. Fortunately, the thrombus rarely extends through the radial artery at the wrist.

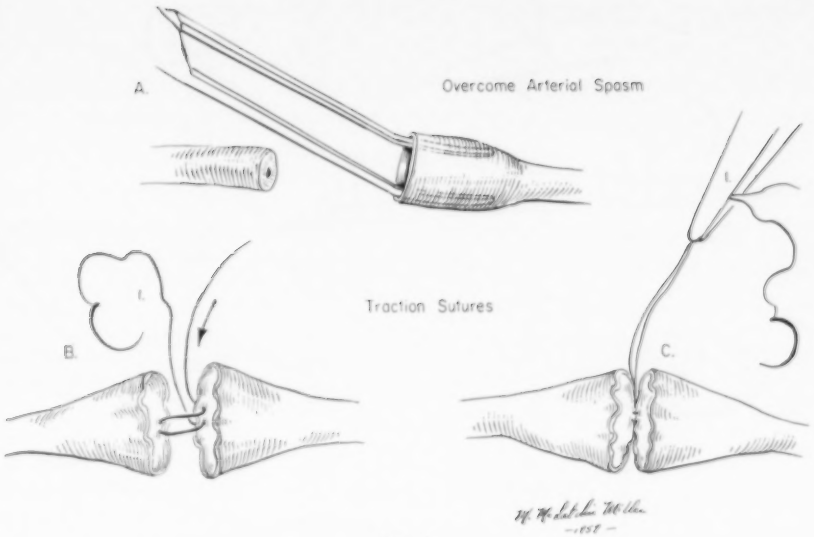

FIG. 2

Local traumatic arteriospasm must be overcome before vessel anastomosis in order to avoid a constricting suture line.

The radial artery at this level, therefore, provides a convenient place to perform such maneuvers in the arm. Retrograde flushing is accomplished by forcefully injecting a large volume of warm heparin saline mixture (ten milligrams per 100 cubic centimeters) in a proximal direction through a No. 15 needle inserted in the artery.

An adherent thrombus may be removed from larger vessels by conventional thromboendarterectomy strippers. In small vessels like the radial artery, a thrombus may be removed with a "pigtail probe" which consists of a spiral at one end of a long piece of blunt-ended No. 22 surgical stainless-steel wire (Fig. 1.) The straight end of the wire is passed up the vessel through the needle hole used for flushing to the proximal arterotomy. The "pigtail" is then drawn through the vessel to remove the clot.

The needle hole may require an adventitial suture for hemostasis, but the vessel must never be ligated.

The failure of peripheral pulses to return following repair of an artery may be due to arterial spasm, but must be presumed to be due to corrigible mechanical or thrombotic obstruction until the nature of the obstruction is demonstrated by an arteriogram made at operation. If the distal thrombosis has extended through the small vessels of the hand beyond the wrist, as may sometimes occur in neglected cases, efforts to restore arterial flow will be fruitless and should be abandoned.

There must be no narrowing at the site of an arterial suture line. There are certain technical considerations in the anastomosis of small vessels like the radial and ulnar arteries which are worthy of consideration here. Such arteries are usually in spasm following injury, and may present the appearance of a piece of spaghetti, being an apparently solid cord of about that size. This smooth-muscle spasm must be overcome before the anastomosis is performed in order to make the circumference of the suture line at least as great as the normally distended vessel. Pharmacological attempts to reverse traumatic arteriospasm are generally unsatisfactory. Dilation of a small artery in spasm can best be accomplished by mechanical distention, performed by very gently spreading the tip of a fine hemostat inserted into the lumen of the vessel (Fig. 2).

In performing the anastomosis it is most convenient to place two stay sutures

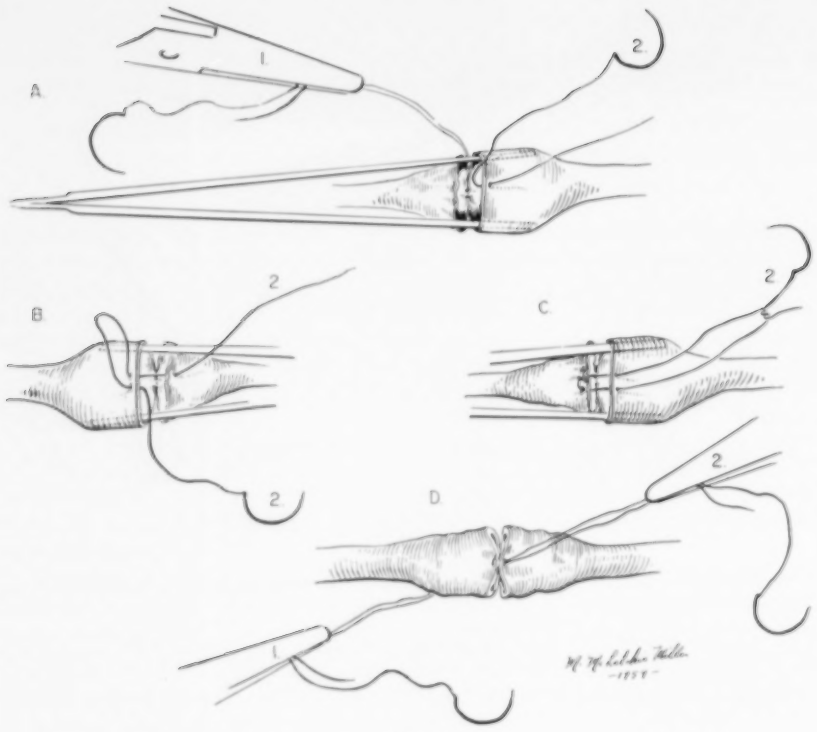

FIG. 3

Stay sutures must be placed with precise symmetry in order to avoid distortion and narrowing of small vessel anastomoses.

at directly opposite sides of the vessel (Figs. 2 and 3). Very fine 000000 silk is best. Placement of the second stay suture is critical, since, if it is off center in one or the other cut end of the vessel, the anastomosis will be distorted and the vessel narrowed. This second stay suture can be accurately placed if the ends of the vessel are stabilized and gently stretched by the tip of a fine forceps inserted as shown in Figure 3. Tension should be taken off the anastomosis when the stay sutures are tied by approximating the arterial clamps which are applied prior to performing the anastomosis to control bleeding. A fine mattress suture is less likely to tear through the arterial wall than a simple stitch. The suture line itself is a simple over-and-over stitch, but this running suture should only be put in while the vessel at the point of anastomosis is maximally distended by traction on the stay sutures (Fig. 4).

Arterial grafts should be used freely if there is loss of vessel length. A graft has a far greater likelihood of success than an anastomosis under great tension. A saphenous-vein autograft is most suitable for the short segment usually required in a traumatic injury and has the greatest chance of long-term success. The direction of the venous valves must of course be considered. Before insertion, spasm in the venous graft must be overcome by distention with saline. If the graft and host artery are cut so as to produce an oblique suture line, there is less tendency to constriction at the anastomosis than there would be if the vessels were cut squarely across. Grafts will elongate when distended by arterial blood, so the second anastomosis should be made under slight tension.

Postoperative thrombosis must be promptly recognized and corrected. If there is excellent flow, reconstruction of a vessel should not fail. Postoperative throm-

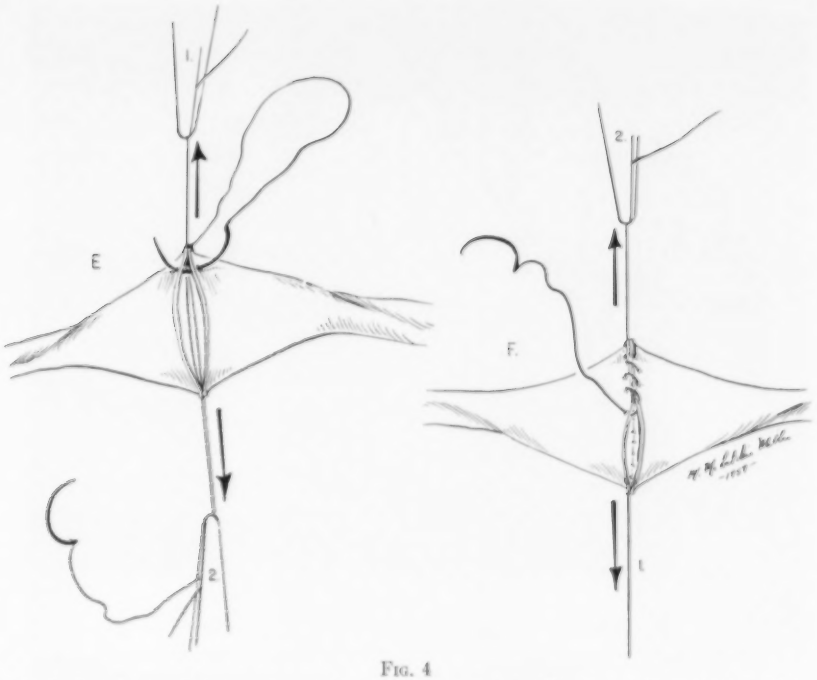

FIG. 4

Stretching the vessel to maximum diameter by tension on the stay sutures during suture avoids suture-line stenosis.

bosis indicates a defect in the anastomosis or an unremoved thrombus. Prompt and aggressive action in the revision of the repair in such cases will result in the salvage of the majority of postoperative failures due to thrombosis. For this reason it is important to observe carefully the peripheral circulatory status at operation while the graft is known to be open, making note of pulses, capillary filling time, color of nail beds, and oscillometry if the site of the injury permits, to provide a reliable base line on which to make the diagnosis of postoperative thrombosis.

The ischaemic extremity should be kept warm during the postoperative period after reconstructive arterial surgery. The undesirability of heat applied to the ischaemic limb has been rightly emphasized, but the equally undesirable nature of cold has not. Heat is dangerous principally because of the likelihood of producing thermal burns, since ischaemic tissue is unable to disperse applied heat because of poor vascular perfusion or to appreciate excessive heat because of sensory defect. That severe tissue injury could be produced by prolonged exposure to only moderate cold had to be relearned by the medical profession with the trench-foot experience of World War II [5]. It is still not generally realized that these lessons are applicable to hospitalized patients. Serious cold injury can result from prolonged maintenance of temperatures as high as 60 degrees Fahrenheit. The practice of keeping extremities cold with ice packs is inconsistent with limb survival and should be undertaken only when the hope of salvage of the limb has been abandoned and amputation must be deferred. It has been demonstrated, especially in the presence of ischaemia, that vessel dilatation may be impossible at temperatures from 60 to 70 degrees Fahrenheit due to the direct effect of cold [1]. A limb temperature of between 80 and 90 degrees Fahrenheit should be sought, since this will allow arteriospasm to subside without danger of increasing the local metabolic demands to beyond what the local circulation can supply. In practice, temperatures of

FIG. 5-A

Case 1. One week after restoration of circulation.

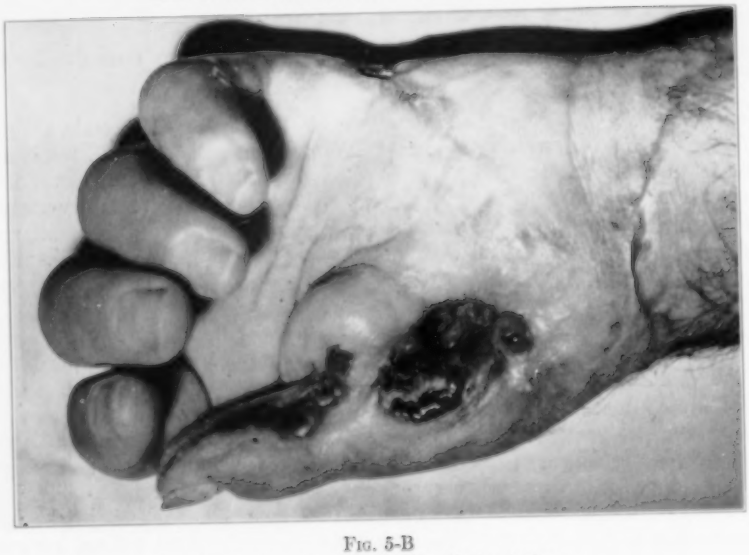

FIG. 5-B

Six weeks after restoration of circulation.

this range may be secured by the nursing staff without the danger of thermal burns by the repeated application of warm blankets to the extremity.

When circulation has been restored after serious ischaemic injury has occurred, expectant treatment with the utmost conservatism in amputation is rewarding. The injury resulting from prolonged temporary ischaemia behaves much like that of frost bite and should be treated with a similar conservatism. Apparently gangrenous skin commonly peels away in time, to reveal pink, new skin below, although deep scarring may be diffuse and severe. A useful extremity may be obtained even though the prognosis for the hand at the time of surgery seemed hopeless.

FIG. 5-C
Flexion and extension possible after one year.

The following two cases will illustrate many of the above principles:

CASE 1. J. C., a florist, thirty-eight years old, fell through a greenhouse suffering a laceration of the left arm with division of the biceps muscle, the median and ulnar nerves, and the brachial artery, as well as a laceration of the left wrist with division of all the flexor tendons to the fingers, the median nerve, and the radial artery. A tourniquet was immediately applied and he was taken to the emergency ward of his community hospital where hemostats were used for hemostasis. Operative repair of nerves and tendons was performed with ligation of the radial artery and end-to-end suture of the brachial artery (under some tension because of the necessity of resecting artery crushed by the hemostat). During the first four postoperative days progressive cyanosis and coldness of the finger tips was visible beyond the dressing. Treatment by repeated stellate ganglion blocks produced questionable change, and on the fifth day he was transferred to the Massachusetts General Hospital. On admission, there was apparent total ischaemia of the entire left hand beyond the wrist. The skin of the whole hand was cold and deeply cyanotic with opaque dead white areas over the hypothenar and thenar eminences. There was frank gangrene of the skin edges at the wrist laceration. Forearm circulation appeared good. At operation on the day of admission, the brachial-artery anastomosis was explored and found to be thrombosed with the distal thrombus extending to the brachial bifurcation. After resection of the anastomosis and extraction of distal clot, the defect in the artery was bridged by a saphenous-vein autograft, with the reappearance of the radial pulse just above the wrist. Postoperatively the hand was kept warm; and, in the course of twenty-four hours, the nail beds of all digits except the thumb gradually became pink. Elsewhere in the hand the appearance was disheartening, the skin remaining dark and ecchymotic. Over the course of two weeks desquamation of the entire hand occurred, revealing full-thickness death of the skin to exist only over the thenar and hypothenar eminences and the tips of the thumb and ring finger (Fig. 5-A). In the subsequent few weeks, a major portion of the hypothenar musculature, the entire musculature of the thenar eminence with the flexor pollicis longus tendon and the nerves to the thumb sloughed, or were debrided as was the gangrenous skin of the finger tip. The resulting granulating surfaces were closed with split-thickness skin grafts leaving the bone of the first metacarpal and the first metacarpophalangeal joint exposed (Fig. 5-B). This exposed bone was eventually extruded as a sequestrum with ultimate healing of the skin. At the end of a year's time good power had returned to the forearm musculature and imperfect sensation had returned to all fingers except the thumb, which was stiff and anaesthetic. There was no return of function in the intrinsic muscles of the hand. Although there was severe fibrosis and stiffness in the hand, the

four fingers were in a position of function and had limited but strong flexion of all joints (Fig. 5-C). The hand was painless and useful in his daily work.

This case demonstrates the undesirability of crushing hemostats for emergency hemostasis, vascular anastomosis under great tension, and failure to promptly re-explore and remedy postoperative vascular thrombosis. It demonstrates the worth of restoration of arterial continuity in the face of apparently irreversible ischaemic injury and the value of conservatism in the treatment of such injury after successful reconstructive vascular surgery. The chances of success of the initial brachial-artery repair might have been improved by repair rather than ligation of the radial artery at the wrist.

CASE 2. T. O'K., a shipper, forty-five years old, fell two floors down an air shaft and through a skylight, suffering a compression fracture of the second lumbar vertebra without neurological change, a Colles fracture of the left wrist and a deep laceration in the lower third of the volar aspect of the left forearm which divided all the volar tendons, the median and ulnar nerves, and the radial, ulnar, and anterior interosseous arteries. He entered the hospital with a tourniquet applied to the arm. This was replaced by a pressure bandage while the initial x-ray studies were performed. At operation, two hours after admission, the fracture of the wrist was reduced and primary repair of the nerves and tendons and the radial and ulnar arteries was performed with prompt and persisting restoration of radial and ulnar pulses at the wrist. The wounds healed by first intention and passive exercises of the fingers and wrist were begun three weeks after injury. One year after injury the circulation of the hand was normal with good radial and ulnar pulses at the wrist. There was excellent return of median and fair return of ulnar, motor, and sensory function. The hand was mobile, undeformed, strong and useful. The patient was troubled only by the lack of fine, discriminatory sensation. During the first six months following injury he was troubled by cold intolerance in the hand, after which this no longer constituted a complaint.

Primary repair of the radial and ulnar arteries possibly saved this man's hand and certainly minimized difficulty with fibrosis and contracture during the convalescent period. It seems unlikely that the problem of cold intolerance would have been so minor in the absence of normal circulation. Foresight on the part of those administering the initial treatment in avoiding further injury to divided arteries greatly simplified the reconstructive procedure.

SUMMARY

A plea is made for primary restoration of arterial continuity in cases of upper-extremity trauma involving injury to major arteries. This is justified by the high incidence of limb loss in such injuries and is particularly important where there is concomitant injury in the distal, relatively ischaemic portion of the extremity. Such efforts can be rewarding even in late and neglected cases. Excellent flow through the reconstructed vessel is essential to success. This requires scrupulous attention to the avoidance of stricture at the suture line and complete removal of distal thrombus in the artery. The latter can be accomplished by retrograde flushing or by the use of instruments from an unthrombosed point in the distal portion of the artery. Re-exploration in the event of postoperative thrombosis is urged since this frequently will convert failure to success if the reason for thrombosis is recognized and corrected. The free use of venous autografts is recommended. Extremes of heat and cold are to be avoided in the extremity with marginal circulation since both can cause serious tissue injury. The extremity should be warmed to a temperature of from 80 to 90 degrees Fahrenheit. Even severe degrees of ischaemic injury resulting from long periods of circulatory arrest will heal and allow salvage of a useful extremity if the circulation is restored. Conservatism is urged in the treatment of such cases.

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Circulation of the Hand, Injection-Corrosion Studies*

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Present-day knowledge of the morphological aspects of the circulation of the hand is based upon information obtained from cadaver dissections, surgical observations, and arteriographic techniques. Each of these methods has definite limitations. Carefully done cadaver demonstrations permit worth-while studies of the larger vessels. However, due to the pliability of the tissues, there is considerable distortion of vascular relationships. The smaller vessels are destroyed by even the most careful dissection and the homogeneity of the surrounding tissue may make the recognition of details very difficult. Observations on living vessels at surgery are usually of even less value. Large and small vessels contract in response to the stimulus of surgery, and the limitations of exposure and the necessity for speed are too real to permit thorough anatomical studies. Arteriographic techniques permit visualization of the living circulation, but outline the larger caliber vessels only. Conway and Stark and Brockis used radiopaque injection media to visualize smaller vessels of the cadaver hand. However, roentgenograms do not allow one to demonstrate soft-tissue relationships. In recent months the authors have become interested in the study of the vascular supply of the hand as demonstrated with one of the newer plastic compounds. The material and techniques are those of Dr. O. V. Batson, of Philadelphia, who has performed extensive studies of various internal organs and their blood supply [1,2]. A liquid plastic is injected into the major arteries of a part. The plastic soon hardens and the specimen is treated with a strong alkali solution. All material other than the plastic and the mineral content of bone is thus removed and there is left a perfect mold of the vascular tree that is rigid enough to permit careful dissection. The advantages of such a technique are outstanding. Soft-tissue structures are easily identified by the outline of their capillary circulation, and vascular relationships can be demonstrated with ease. A three-dimensional model is available with accurate detail of the entire vascular tree down to and including capillaries.

The purpose of this paper is to present observations made by the authors upon such specimens. More detailed studies are under way, particularly in reference to the arteriovenous anastomoses of the hand.

* Read at the Annual Meeting of the American Society for Surgery of the Hand, New York, N. Y., February 1, 1958.

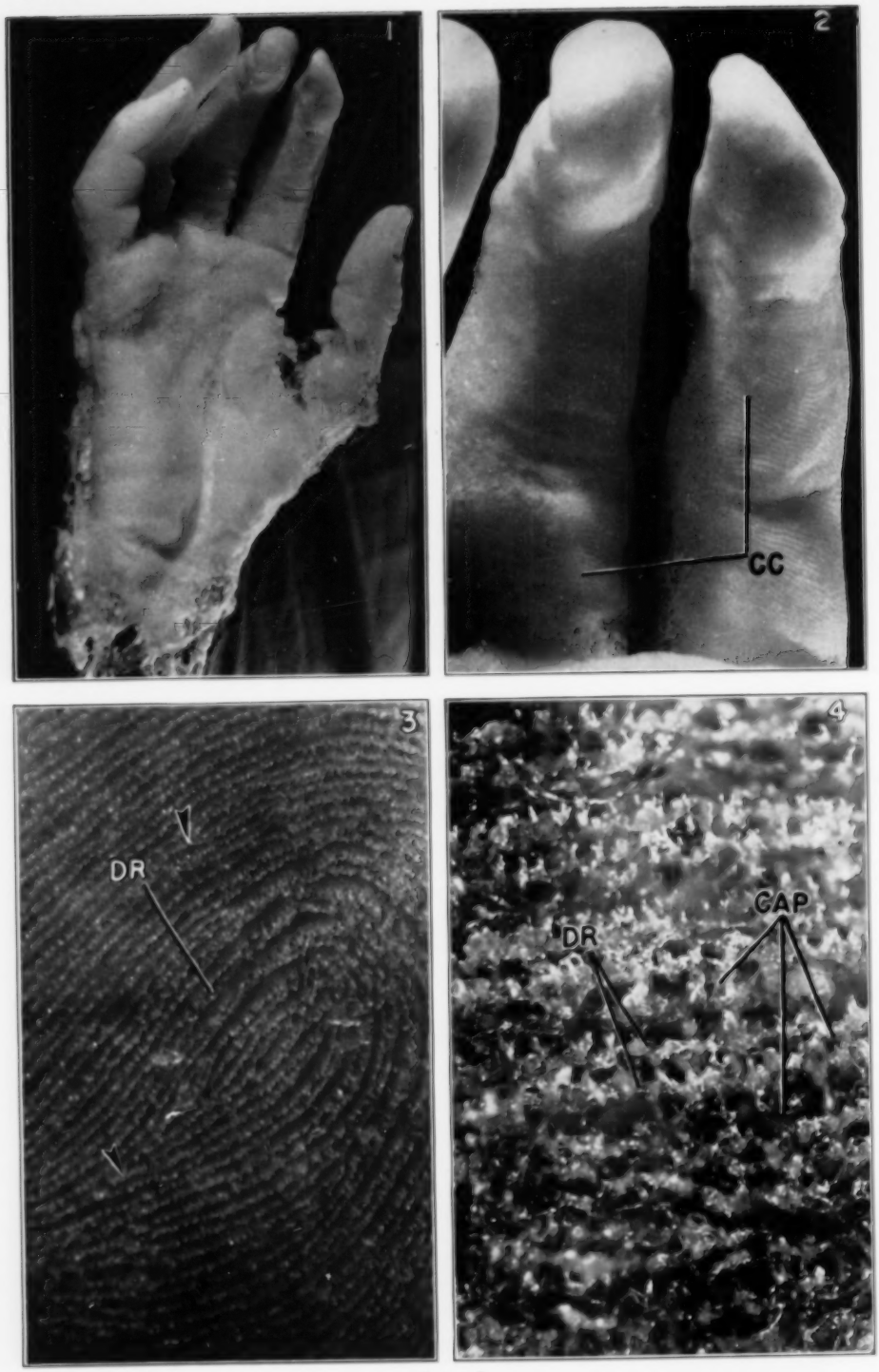


PLATE I

Fig. 1: This predissection view of the plastic cast of the vascular bed of a fourteen-year-old boy (Specimen 4) bears a striking resemblance to the intact hand.

Fig. 2: Even slight magnification of the index and long fingers reveals the cristae cutis (*CC*) of the dermal whorls.

Fig. 3: Greater magnification demonstrates that each dermal ridge (*DR*) is doubled. Note the branchings of the longitudinal vessels in the cristae cutis (arrows) (about × 6).

Fig. 4: Each dermal ridge (*DR*) gives rise to the central vessels in the papillae corii. Only a few of the capillaries (*CAP*) are still visible (about × 23).

TECHNIQUE AND MATERIAL

Seven hands form the basis for this report; three of them were normal. Specimen 1 was the right hand of a male Negro laborer, thirty-five years old, from the service of Dr. J. L. Goldner of Duke Hospital. Amputation was performed through the wrist. The hand was stiff, useless, and painful because of a stretch palsy of the brachial plexus secondary to severe trauma producing multiple compound fractures of the humerus, the forearm, and the metacarpals. The patient had traumatic amputation of the index and long fingers.

Specimen 2 was obtained from the service of Dr. Roy Hoover of Roanoke, Virginia. The patient was a male Negro, twenty-five years old, who had total brachial plexus palsy on the left of eight years' duration.

Specimen 3 was obtained from the service of Dr. Walter Hunt of Raleigh, North Carolina. Disarticulation was performed through the shoulder in a fifty-year-old female with intractable pain secondary to carcinoma of the breast.

Specimen 4 resulted from the accidental disarticulation at the wrist of the right hand of a fourteen-year-old boy who fell into a rotary lawnmower. It was obtained from the service of Dr. R. E. Lewis, of North Wilkesboro, North Carolina.

Specimen 5 is the left hand of a white female, seventy-four years old, whose left arm had been disarticulated at the shoulder for fibrosarcoma involving the humerus. It was obtained through the courtesy of Dr. Warren Tiller of Spartanburg, South Carolina.

Specimen 6 was the right hand of a white male, forty-three years old, whose arm had been removed by Dr. Richard Dodelin of Duke Hospital, because of fibrosarcoma of the humerus.

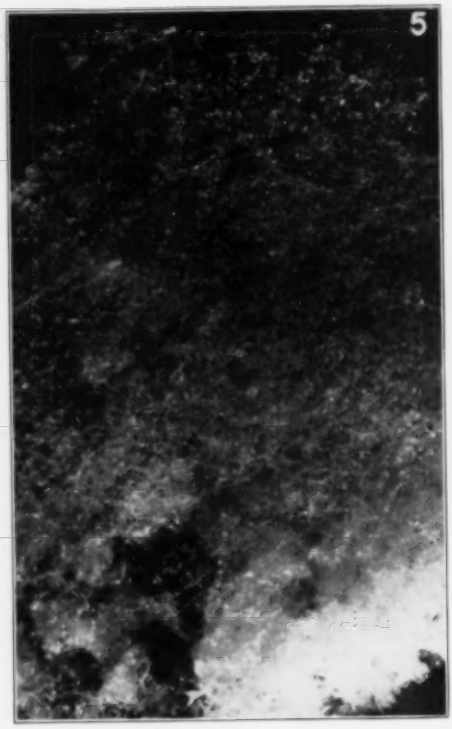
Specimen 7 was contributed by Dr. Wayne Lee of Charlotte, North Carolina. It resulted from traumatic amputation by a punch press through the left mid-forearm in a Negro male, forty-one years old.

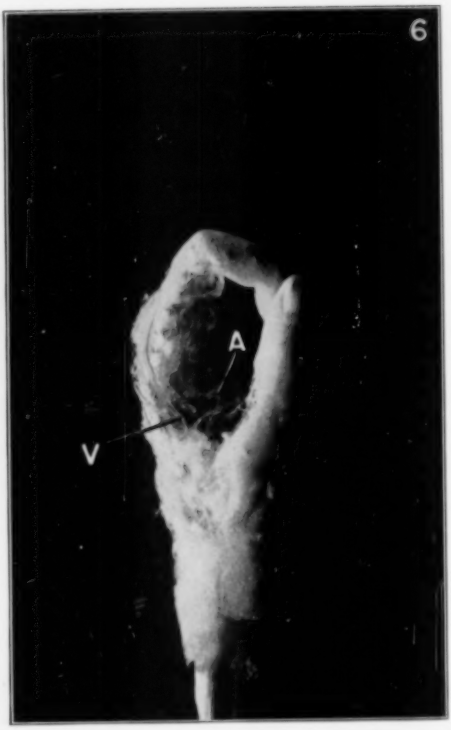
In Specimens 4 and 7 there had been no pathological process present in the limb prior to traumatic amputation.

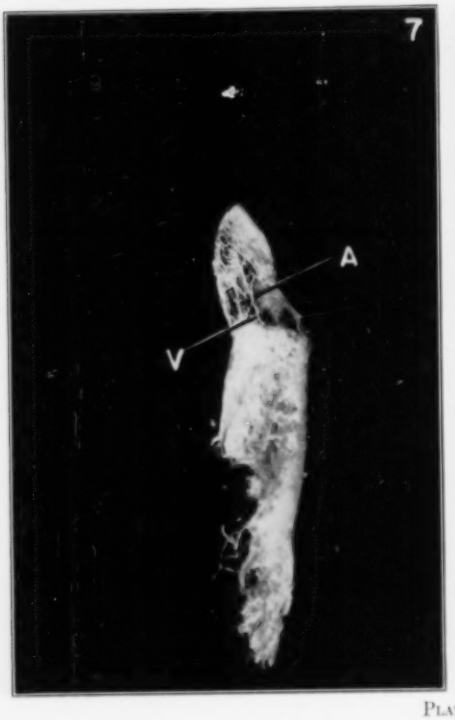
Injection of the radial and ulnar arteries was carried out after both arteries had been flushed with about 500 cubic centimeters of normal saline. In the seven specimens the injection was begun fifteen minutes, five minutes, fifteen minutes, twenty minutes, fifteen minutes, twenty minutes, and five hours, respectively, after amputation. These specimens were allowed to harden from three days to three weeks and were then suspended in a 30 per cent solution of potassium hydroxide for a minimum of fourteen days. Four of the specimens required additional treatment with potassium hydroxide. After digestion had occurred, the specimens were gently washed with running water for at least one week.

The plastic compound used was Batson's Corrosive Solution Number 17. Excellent plastic casts were obtained. The specimens were painstakingly dissected by using ophthalmic surgical instruments and magnifying lenses. Photographs were made at various stages of the dissections and were supplemented with observations made by the authors. Photographic prints were labeled within forty-eight hours to avoid inaccuracies.

After completion of the dissection of the dermal vessels in Specimens 3 and 4, the volume of the vascular bed was measured quantitatively in terms of milliliters of plastic (the plastic casts of the vessels) per square centimeter of der-







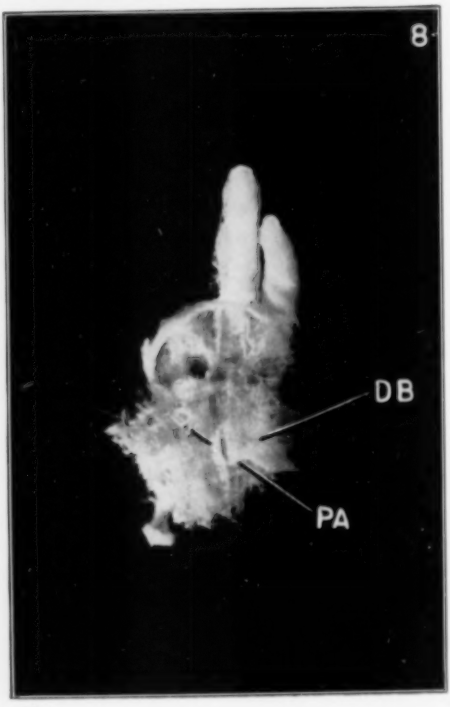


PLATE II

Fig. 5: This view of the dermal bed on the dorsum is presented for comparison with Figure 3. The magnification and orientation are the same. The lack of longitudinal channels related to the cristae and of branches related to papillae results in a strikingly different appearance and gives the impression of an irregular arrangement of the vascular bed.

Fig. 6: The radial part of the vascular bed in the palm of the hand drains around the radial border. Note that this venous plexus (*V*) lies more superficial than the arteries (*A*) which supply the adjacent surfaces of the index finger and thumb.

Fig. 7: The extensive venous drainage (*V*) of the finger tip lies more superficial than do the digital arteries (*A*).

Fig. 8: In the region of the palm, there are two well developed vascular beds: the previously mentioned dermal bed (*DB*) and a deeper one which is related to the palmar aponeurosis (*PA*).

mis. The area of the dermis was determined by a photographic technique in which the completely dissected dermis was removed in approximately square portions and the area of each portion determined by projecting photographs of known magnification of each portion and measuring the area with an electronic planimeter and graphoscope. The volume of the vessels in each portion of the dermis was determined simply by weighing each portion of the dissected dermis and calculating the volume of the plastic casts of these vessels from the weight and the specific gravity of the plastic.

OBSERVATIONS

The total vascular bed was injected in these specimens. As seen from the surface (Figs. 1 through 5), the vessels within the dermis are completely filled with the injection medium. The cast of these vessels bears a most striking resemblance to the intact hand.

The vascular bed within the papillary layer blends insensibly with that within the reticular layer of the dermis. The subcutaneous fatty layer is relatively avascular. Quantitative studies will be required to demonstrate the precise distribution of the total vascular bed, but we have found that as much as a third of the total vascular bed of the hand may be located in the skin.

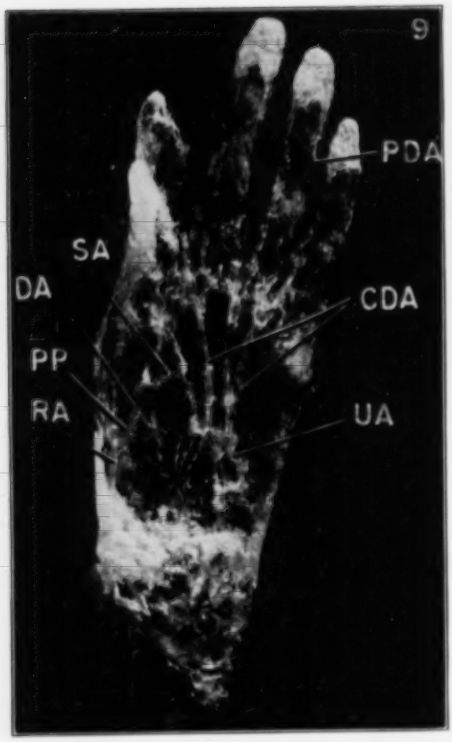
The vascular bed of the dermis is both thick and dense as was demonstrated in Specimens 3 and 4 by removal of the entire dermal bed. In the hand of the fifty-year-old female (Specimen 3) this bed on the dorsum of the hand had a volume of approximately .015 milliliter per square centimeter of surface, whereas on the palmar surface this volume was approximately .029 milliliter per square centimeter. The skin of the fourteen-year-old boy (Specimen 4) was considerably thinner, the volume of the bed being about .010 milliliter per square centimeter on the dorsum and .019 milliliter per square centimeter on the volar aspect.

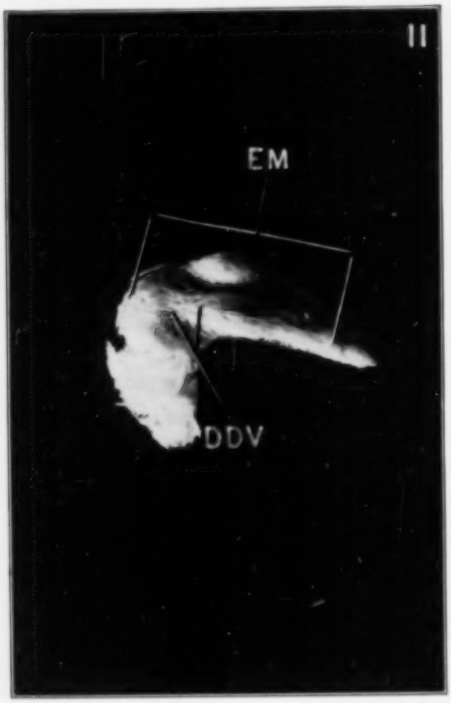
The total volume of the vascular bed of the dermis of the fifty-year-old female was greater than that in the fourteen-year-old boy. However, the ratios of the volume on the dorsal surface to that on the volar surface were almost identical in the two hands—that in the former being 0.51 and in the latter, 0.52.

At least two factors contribute to the greater volume of the dermal vascular bed on the volar surface: (1) the well known greater thickness of the dermis on the volar surface, and (2) the greater density of vessels here. The greater density of the volar dermal vessels is related to the greater regularity of their arrangement. Figures 3 and 4 demonstrate that on the volar surface the vessels within the dermal ridges (cristae cutis) and the papillae corii are distributed according to the well known fingerprint pattern. On the other hand, the superficial vessels in the dermis on the dorsal surface are distributed irregularly (Fig. 5).

The dermal vascular bed is drained by veins which join to form a venous network lying in the deeper part of the subcutaneous layer (Fig. 7). This venous network drains primarily ulnarward and radialward (Fig. 6) to the dorsum of the fingers and hand.

In contrast to the venous drainage of the skin, the arterial supply is strik-





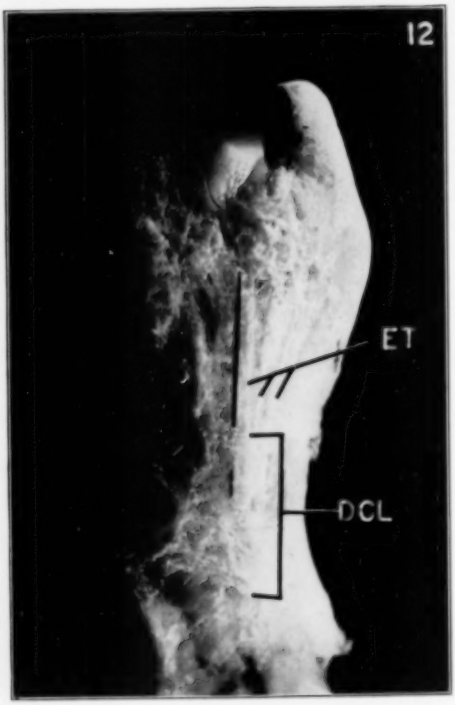


PLATE III

Fig. 9: The superficial palmar arch (*SA*) lies beneath the palmar aponeurosis which has been removed, and is formed largely by the ulnar artery (*UA*), but is completed by the superficial palmar branch of the radial artery (*RA*). The palmar digital arteries, or common digital arteries (*CDA*), arise from the superficial palmar arch. Note princeps pollicis (*PP*) arising directly from the radial which continues ulnarward to form the deep arterial arch (*DA*). Note the tortuosity of the proper digital artery (*PDA*).

Fig. 10: The two proper digital arteries (*PDA*) to the index finger anastomose at the level of the lunula (*L*). Note the size of this anastomosis (*A*) and the uniform caliber of the vessels as they approach it.

Fig. 11: The extensor mechanism (*EM*) of the fingers contains an extensive vascular bed. This lies subjacent to the dorsal digital veins (*DDV*) which run in the subcutaneous vascular bed.

Fig. 12: A less dense vascular bed lies superficial to the extensor tendons (*ET*) on the dorsum of the metacarpal region and is somewhat more dense within the dorsal carpal ligament (*DCL*). A needle lies beneath the latter.

ingly different. In many areas, it lies at a much deeper level (Fig. 9) and, in general, the arterial branches come off at right angles to the undersurface of the skin (Fig. 10). In the distal part of the fingers, these right-angle branches originate deep in the pulp and pass through almost the full thickness of the pulp in order to reach the dermal vascular bed.

This general pattern of arterial supply by deep arteries which give off right-angle branches seems to be reproduced in the palm. Here there are two vascular beds: the one previously mentioned in the dermis and a deeper bed related to the palmar aponeurosis (Fig. 8).

The tendons and their restraining apparatus are well vascularized. The extensor mechanism of the fingers is permeated by an extensive vascular bed which (Fig. 11) lies subjacent to the dorsal digital veins. This extensive vascular bed is continuous proximally with two other beds (Fig. 11), one enclosing and permeating the extensor tendons on the dorsum of the hand, the other being in relation to the dorsal carpal ligament (Fig. 12). Although they are not illustrated here, the flexor tendons and their restraining structures are equally well vascularized.

Most of the channels of the vascular beds of the tendons run in the same direction as the fascicles of the individual tendons, and have the appearance of being placed between the fascicles. The arrangement of these channels within the tendons gives this vascular bed an appearance of regularity. Conversely, within the transverse carpal ligament and other similar restraining structures, the main channels are characterized by many random crossings and have the appearance of irregularity.

DISCUSSION

In this study the plastic was injected according to the method of Batson [1,2] and resulted in a perfect mold of the entire vascular tree of the hand after all the soft parts had been removed by treatment with a strong alkali solution. Because the entire vascular tree is injected, this study differs from that carried out by Shapiro who visualized only the arterial side of the circulation to the brain by means of plastic injections.

Our observations are largely qualitative in nature and are based upon seven hands. Consequently, it would be premature to arrive at conclusions that are pertinent to the functional significance of the various component parts of the blood supply of the hand.

In previous studies using similar plastic-injection techniques in experimental animals, Knisely and his associates demonstrated that it is possible by dissecting out the plastic cast to determine precisely the proportion of the vascular bed which is related to each functional component of the body, organ, or part. By this same method they also determined the total vascular space in rats and its distribution in three sizes of blood vessels. Such a study is now under way to de-

termine the functional significance of the blood supply to each component of the hand.

Because of the limitations of this study, it is possible only to draw attention to a few generalizations which may be summarized as follows.

SUMMARY

1. On the basis of the study of seven hands, it appears that this plastic-injection technique can be used to further elucidate the relative vascularity of the component parts of the normal and abnormal hand.

2. As much as one-third of the total vascular bed of the hand lies within the dermis. The volume of the volar dermal vascular bed is approximately twice that of the dorsal vascular bed.

3. There are significant differences in the distribution of the arteries feeding and of the veins draining the vascular bed of the hand. The arteries, in general, lie at a deeper level giving off branches which approach the skin at right angles. On the other hand, the veins lie in a plane of the dermal bed and are separated from it by only a layer of loose connective tissue containing a variable amount of fat.

4. The connection between the distal ends of the proper digital arteries is of interest and worthy of further study because it is of large size, the caliber of the approaching vessels is surprisingly uniform as they near the actual anastomosis, and they bear a surprising resemblance to the arcades which supply the small intestine except that they give off right-angle branches in two planes rather than in one plane.

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Reconstruction of Congenital Abnormalities of the Upper Extremities*

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Congenital abnormalities comprise a field of reconstructive surgery that taxes the ingenuity of the surgeon and stimulates continual search for newer methods and concepts to provide useful function and acceptable appearance. Abnormalities of the upper extremities are especially varied in their manifestation, producing bizarre combinations of duplication, absence, and imbalance which make neat classification rather difficult. Moreover, some deformities are so complex that it is difficult to decide which is the predominant one. Although many classifications exist, those generally accepted have a number of limitations because of their long-winded, polyglot, polysyllabic terminology not based on the causative agents. A classification based on etiological factors would be of help, but in many of these conditions the causative agent is not known; many conditions in which the manifestations appear to be diverse do have a similar cause of origin, and in many conditions with identical etiological factors the ultimate deformities appear to be quite different. Moreover, any classification that attempts to be all-inclusive inevitably becomes involved and complicated.

In spite of these difficulties, inherent in any classification, an attempt is made here to offer a modified classification, which is justified by:

1. Simplicity: clinical and anatomical manifestations are used as the criteria to classify the local condition.

2. Clarity: English terminology is used. (Latin and Greek terminology are retained parenthetically to assist in leveling linguistic barriers.)

3. Practicality: by emphasizing the derangement of function and structure the purpose of this classification is to crystallize the particular reconstructive procedure needed.

Although not all-inclusive, this classification has the advantage of avoiding monotonous enumeration of isolated entities.

CLASSIFICATION

Despite limitations, this classification is divided into four main parts, namely:

1. Local abnormalities confined to upper limbs.

2. Conditions affecting the skeleton as a whole.

3. Conditions in which the greatest disturbance is localized in the neuromuscular system.

4. Miscellaneous conditions not belonging to the groups mentioned previously.

By far the most difficult and time-consuming part of the preparation of this paper was the compilation of the cases into some orderly form to permit grouping and subdivision and to avoid an endless cavalcade of non-related items. Congenital abnormalities of the upper extremities are so multitudinous that no classification can be complete and consistent. Moreover, the various subdivisions are not always of equal value and some of the less important related entities are grouped under the non-committal heading of others or miscellaneous.

In this classification, where no number appears under a particular subdivi-

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TABLE I

CLASSIFICATION OF ABNORMALITIES OF THE UPPER EXTREMITIES ONLY IN SIXTY-ONE PATIENTS

Anomaly		No. of Cases
A. Absence of Parts (Agenesis or Amputation)		
Vertical absence (long axis of the limb)		
No arm (abrachius)		2
No forearm or hand (hemibrachius)		3
No hand (achirus)		8
No digits (adactyly)		8
No phalanges (ectrodactylism)		
Horizontal absence of parts (forearm and hand)		
No forearm (phocomelia)		16
No radial component (radius and thumb)		
No radius or thumb	7	
No radius or its parts	1	
No thumb	3	
No part of thumb (hypoplasia)	5	
No medial component (central digits and carpal bones)		6
No ulnar component (ulna and three ulnar digits)		
B. Deformities or Abnormalities		
Shoulder girdle		4
Upper arm		
Forearm		6
Radio-ulnar fusion	4	
Madelung's deformity	1	
Others (mirror-hand)	1	
Hand and digits		40
Bone fusion (symphalangism)	7	
Bent digits (clinodactyly)	4	
Short or partially amputated digits (brachydactyly)	8	
Webbed digits (syndactyly)	14	
Others (bifid and supernumerary digits)	7	
Total		93

sion, the implication is that either the patients were not admitted to the hospital or that the information was not available at the time of compilation. Some deformities were not clear-cut, being ill-defined combinations of several things; in these cases, the most predominant feature was selected as the basis for classification.

Not all deformities either require or attain operative treatment. Some patients with severe congenital abnormalities affecting the hand or forearm do develop an amazing dexterity, which compensates for their deformity. Some get along reasonably well but are brought in by eager parents who clamor for more nearly normal appearance. Our policy has been that no useful function of the hand is ever sacrificed to attain conventional appearance. Occasionally, patients with a corrigible deformity were also afflicted by poor or retarded mentality and were not considered suitable candidates for complex reconstructive procedures. Such patients were not admitted to the hospital and consequently will not be included in this group of cases.

About half of the total number of the 120 patients in our series had abnormalities of the upper extremities only. However, several anomalies were occasionally found in the same limb and sometimes, in patients with bilateral abnormalities, the defects were not identical in both limbs. Ninety-three anomalies were found among the sixty-one patients of this group (thirty-six males) and these are compiled under various headings in Table I. Of the total number of these anomalies, forty-three were grouped under absences (vertical and horizontal, subgroup A) and fifty were listed as deformities and abnormalities (subgroup B).

TABLE II

GENERAL AFFECTIONS OF THE SKELETON INVOLVING THE UPPER LIMB OF SIXTEEN PATIENTS AND NEUROMUSCULAR CONDITIONS WITH ANOMALIES OF THE UPPER LIMB OF FORTY-THREE PATIENTS

Skeletal Conditions		No. of Cases
I. Disturbances of Bone Formation or Growth		
Chondrodystrophies		
Dyschondroplasia (multiple enchondroma or Ollier's disease)		2
Achondroplasia (chondrodystrophy foetalis)		5
Chondro-ectodermal dysplasia (Ellis-van Creveld syndrome)		2
Metaphyseal and epiphyseal dysplasia		
Chondro-osteo dystrophy (gargoylism and Morquio-Brailsford disease)		1
Osteodystrophies		
Osteogenesis imperfecta		2
Others		
Arachnodactyly (Marfan's syndrome)		2
Disturbances of Joints and Ligaments		
Multiple dislocations		2
II. Neuromuscular Conditions		
Arthrogryposis (amyoplasia congenita)		8
Sprengel's deformity		4
Cerebral palsy		29
Spastic hemiplegia and quadriplegia	28	
Athetosis	1	
Others		
Möbius' syndrome (facial muscles and upper extremities)		2
Total		59

Fifty-nine patients had deformities of the upper limbs as a direct sequel of some congenital systemic disturbance, or in association with it, and these deformities are grouped under various subdivisions in Table II. The group of sixteen patients with conditions affecting the whole skeleton were divided into three subgroups based on the concentration of greatest disturbance, namely: cartilage or bone formation; joint formation; or some other aspect (Group I). Anomalies of the neuromuscular system were present in a group of forty-three patients (Group II); of these, patients with cerebral palsy made up the largest subgroup.

Neither the total number of patients nor the numbers under the various subdivisions indicate the incidence of abnormalities in the population area from which these patients originate (Central and Eastern Canada and Northeastern United States). The numbers do not really reflect the incidence of hospital admission because not all of the patients were seen and treated by me. However, the distribution of the types of deformities in this group was somewhat similar to that reported by Birch-Jensen, who analyzed all the cases of congenital abnormalities of the upper extremity occurring in the entire population of Denmark (about 4,000,000).

ETIOLOGY

No attempt is made to discuss the etiology of these congenital abnormalities because: detailed information regarding the pedigree was not always available for our patients and occasionally was incomplete, and it was not possible in these cases to make a distinction between the so-called endogenous (aplasia due to defect of germ plasm) and exogenous (intra-uterine conditions) types of anomalies of the limb. These criteria have been used as the basis of etiological classification of some congenital abnormalities of the upper extremities by some authors [2,3,6]. We found that presence of scar is not a reliable criterion for endogenous type of amputation. Moreover, some of the so-called exogenous defects

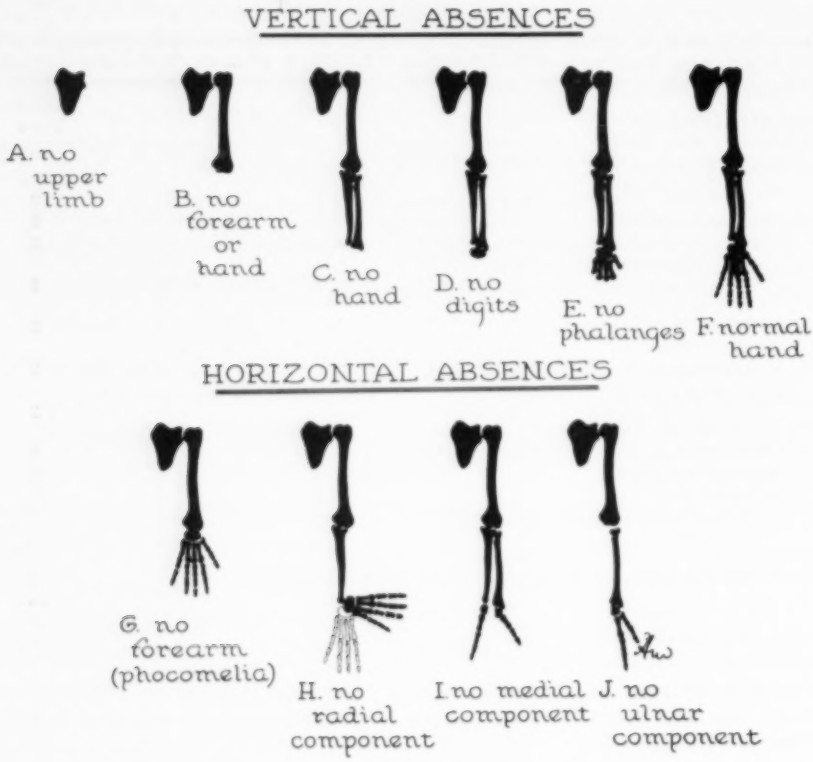

FIG. 1

Diagrammatic representation of vertical and horizontal absences, which were used in the classification of some of the anomalies of the upper limb. (See text.)

occur symmetrically and have been demonstrated to have familial occurrence in siblings, thus suggesting an inherited characteristic. Unfortunately, no data are available on whether the specific deformity that had no previous occurrences in the family would be transmitted to the progeny of the patients in this study, since most of them were preadolescent.

The anlage of a given organ in the developing foetus is more susceptible to environmental stress (such as noxious agents and hypoxia) during the period of most rapid development. On the basis of experimental work and analysis of congenital malformation in man, Ingalls pointed out that certain anomalies of the upper limb are more likely to occur in the following periods of gestation: absence of limb in the third and fourth weeks; carpal ablation in the fifth and sixth weeks; digital ablation in the seventh week; and digital stunting in the eighth week.

Because of the length of time since the birth of some of the patients, the information bearing on the gestation history was not complete or not reliable. It is obvious that, considering the complexities of human genetics, any discussion of etiology based on incomplete data is unjustified.

GENERAL APPROACH TO RECONSTRUCTION

The primary aim of reconstruction is to provide the basic need of the limb —namely, good skin cover with adequate sensation, useful pinch and grasp, and ability to place the hand in a strategic position. These basic needs must be provided through a minimal number of surgical procedures to be practical. In gen-

eral, a normal appearance was not the goal; stress was laid on the improvement of function, and elaborate surgical procedures were avoided.

A major part of the reconstructive procedures was confined to the provision of bone support or stabilization, phalangization of fused digits by shifting of local or distant skin, transfer of digits to provide pinch and grasp, and muscle transfer to give motion to newly constructed parts. In some cases, transfer of composite structures involving several tissues was required.

In that type of deformity that was represented by only one patient it was not possible to appraise other methods of management. However, it might be of value to report the experience of using one particular method (not necessarily one of choice), amplified by the observation extending over the entire period of follow-up since the beginning of treatment. In certain cases it was possible to conclude whether it would be worth while to use the same method again or whether one should look for different or improved methods.

It will not be possible within the limits of this article to discuss the treatment of all abnormalities encountered in this series or to dwell on the technical details of the specific surgical procedures used in each case. Consequently, the discussion will be confined to a few selected cases, which will illustrate the complexities of reconstructive procedures and will stress the selection of methods used to provide for the functional needs of the individual patient.

ABNORMALITIES OF THE UPPER LIMB ONLY

Absence of Parts (Agenesis or Amputation)

For clinical simplicity and practicability, the absence of parts is compiled under two headings: vertical and horizontal (Fig. 1). The upper limb is subdivided into five anatomical components in the ascending or vertical direction in relation to the long axis: phalanges, digits, hand, forearm, and upper arm, and the various deformities are grouped under these divisions. Generally, the vertical absences were found to be much more difficult to reconstruct than the horizontal absences; indeed, true reconstruction was practical only if the digits or phalanges were absent (Figs. 1, *D* and 1, *E*).

Vertical Absences

Total absence of the upper limb—the most severe form of absence in this group (Fig. 1, *A*)—had not been seen in our hospitals, probably because this is not considered a problem of reconstruction and consequently patients are not referred for treatment. Birch-Jensen found that in Denmark 1.6 per cent of a total of 625 cases fell into that group. Two cases of absence of the forearm and hand were present in the patients in this study, but generally no specific treatment was recommended. (In bilateral absence of forearms and hands, it might be practical to provide cineplastic prosthesis in early childhood, thus providing accurate muscle control for grasping motion.)

Four cases of total absence of the hand were encountered in this series; for these, a Krukenberg procedure in a case of unilateral involvement provides a stabilizing organ for support and grasping that functions, however, only as a secondary hand. This procedure was not carried out by me, but it is thought to have some merit and is favored in Europe [6].

Reconstruction of the missing fingers is one of the more difficult procedures in the treatment of deformities of the upper extremities, especially if there is also absence of the thumb. There were eight cases of digital absence in this series. The two methods that were tried for correction of these deformities were the transfer of toes as a composite flap and the extension of the length of the hand by pedicle flap and bone strut. Both methods have limitations and disadvantages. Although transplantation of toes does provide finger-like structures with nails and a variable amount of joint motion, there is some disfigurement of the foot when more than one toe is used.

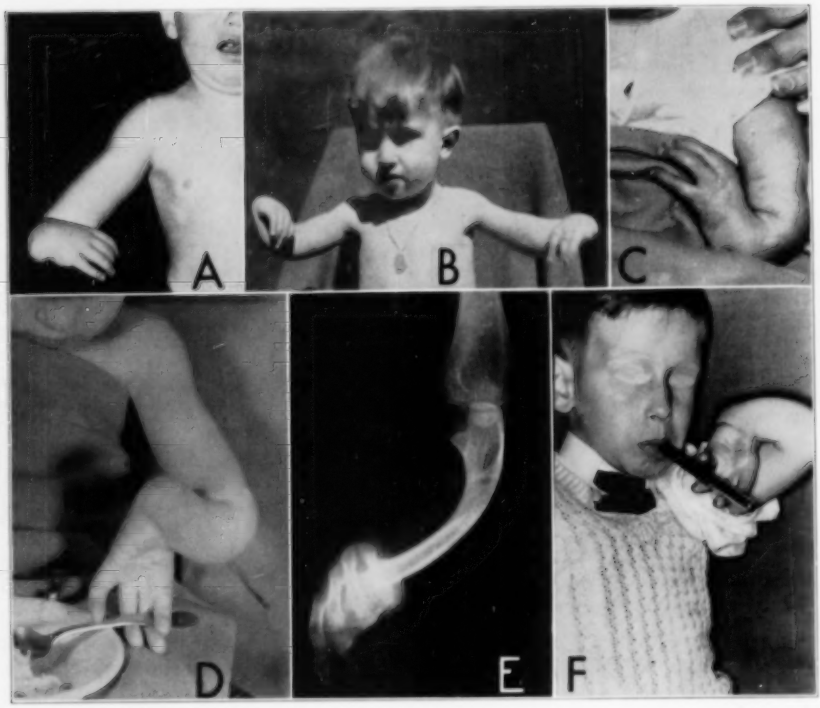

FIG. 2

Various degrees of deformities of hand and forearm, due to congenital absence of the radius and thumb.

Fig. 2, *A:* Absence of the radial component in the right arm of a two-year-old girl. The hand is held at the right angle to the long axis of the forearm.

Fig. 2, *B:* Bilateral absence of radial components in a three-year-old boy. Note the beginning of spiraling of the ulnae.

Fig. 2, *C:* Severe degree of distortion, owing to the absence of the radial component in a two-year-old boy, showing bowing of the ulna.

Fig. 2, *D:* Severe deformity, owing to absence of the radial component in a four-year-old boy. There is spiraling and bowing of the ulna, which results in a pronated position of the hand.

Fig. 2, *E:* Roentgenogram of the forearm shown in D.

Fig. 2, *F:* Extreme distortion of the forearm, associated with absence of the radial component in a seven-year-old boy that had not been treated. No pinch or grasp was possible, because of absence of the thumb and severe contraction of flexor muscles. Photograph shows position of the limb while the child was attempting to reach his mouth.

Phalanges were absent in eight patients. This anomaly is frequently accompanied by other deformities, such as webbing, banding, and bone fusion. If distal phalanges alone are absent, reasonably good function is achieved even without correction of the length of the fingers, provided the other associated deformities are corrected. However, absence of two phalanges of the thumb requires some type of reconstructive procedure to lengthen the thumb, to provide useful pinch and grasp. Considerations of specific procedures for the reconstruction of absent digits will be commented on after discussion of the horizontal absences of the forearm and hand.

Horizontal Absence of the Forearm and Hand

Developmentally speaking, the forearm and hand are divided into three anatomical areas of activity which are almost parallel to each other in location. These are: the radial component, which forms the radius and the thumb along with the carpal bones between them; the medial component, made up of the central carpal

FIG. 3

Variations of degree and extent of anomalies, associated with absence of the radial component.

Fig. 3, *A:* Complete absence of radial and thumb rays.

Fig. 3, *B:* Absence of the thumb ray and hypoplasia of the radius. (Note the fusion of the upper ends of ulna and radius.)

Fig. 3, *C:* Absence of carpal elements of the thumb and hypoplasia of the thumb.

bones and the index finger; and the ulnar component, which consists of the ulna and the three ulnar fingers with their carpal bones [16]. Each of these anatomical areas can be involved adversely during embryonic development, producing deformities confined to the particular area affected (Fig. 1). The abnormalities vary from complete absence of all components of the affected part to slight abnormalities involving only a portion of the long bone or of the digits.

Absence of the Forearm (Phocomelia)

This curious condition is characterized by absence of all structures of the forearm, so that the hand articulates with the humerus. The anomaly is bilateral in about half of the patients and occasionally is associated with deformities of the lower limbs. Various combinations of the deformities of the hand have been noted [3,6]. This anomaly was not seen in our group of cases.

Absence of the Radial Component

Excellent treatises on absence of the radial component have appeared, describing the pathogenesis of this abnormality and its variations [4,13,19,20]. Three cases were singled out from this series because they illustrate the methods used in treatment and stress the long-term procedures required, frequently bridging about fifteen years.

Considerable variation in the severity of this deformity was encountered in this group of patients (Figs. 2 and 3). Ordinarily, the patients with radial deformity were presented for treatment shortly after birth, because of the obvious nature of the anomaly. If that is the case, I favor applying a light splint to maintain the alignment of the hand with the forearm. If that is not immediately possible, because of shortening of muscles and skin, soft-tissue lengthening and, possibly, Z-plasty to the skin are carried out first (Fig. 5). The light, elastic splint does not interfere with the use of the hand, can be easily adjusted, does not cause skin irritation, and was found to be well tolerated by all patients [9]. I prefer to provide bone stabilization to the wrist by the transfer of autogenous

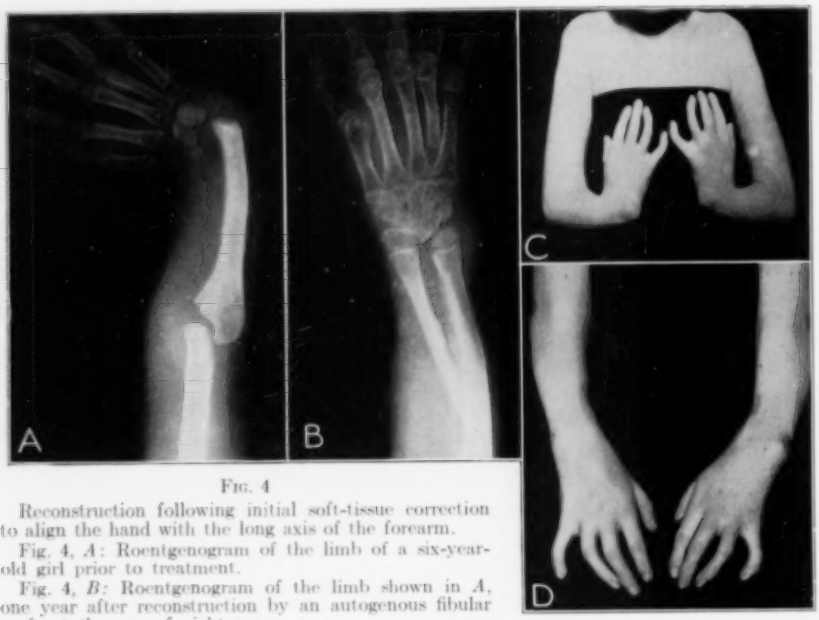

FIG. 4

Reconstruction following initial soft-tissue correction to align the hand with the long axis of the forearm.

Fig. 4, *A*: Roentgenogram of the limb of a six-year-old girl prior to treatment.

Fig. 4, *B*: Roentgenogram of the limb shown in *A*, one year after reconstruction by an autogenous fibular graft at the age of eight years.

Fig. 4, *C*: Preoperative appearance of both hands in the same girl, showing deformity owing to radial absence.

Fig. 4, *D*: Appearance of right and left hands after reconstruction by bilateral transfer of autogenous fibulae in the same girl, at eleven years of age. The left hand was operated on at the age of seven; note the recurrence of the radial deviation of the hand. The right hand was reconstructed at the age of eight. Almost normal function of the hands was attained.

fibula [20]. In this series, this procedure was not done in children younger than four years of age. Prior to the insertion of the bone graft, traction is applied to the hand through a Kirschner wire, to advance the carpal bones distal to the ulna, thus providing space to accommodate the transferred fibular head. When this is not done, there is a greater likelihood of recurrence of radial deviation of the hand, owing to the greater rate of growth of the ulnar bone.

These procedures were followed in a patient with bilateral radial absence in whom two fibular grafts were transplanted one year apart to both hands (Fig. 4). Fusion of the wrist had not been done in any of the eight cases of complete radial absence, a procedure that is followed by some writers [1,14], but one that is likely to stunt the growth of the forearm; this is undesirable in a limb that usually has some shortening when compared with the normal. At a later date, osteotomy of the curved ulna was required in several of the cases, when recurrence of the radial deviation of the hand became apparent.

If the thumb is present, improvement of pinching and grasping takes place soon after bone transplantation. However, if the radial absence is complicated by absence of the thumb, then further reconstruction is required after the initial soft-tissue release and subsequent stabilization by bone-grafting has been carried out. Provision of a thumb for a hand that has little active flexion, because of extensive contraction and fibrosis of the digital flexors, constitutes as difficult a project as the initial alignment of the hand for radial absence. Indeed, in one patient, the fifth digit was shifted away from the palm, to provide thumblike grasping and pinching motions, because the index finger was rigid in all joints and not suitable for pollicization. When the fifth finger was shifted to a position of abduction and opposition, good pinching and grasping movements ensued (Figs. 5, *D*; 5, *E*; and 5, *F*).

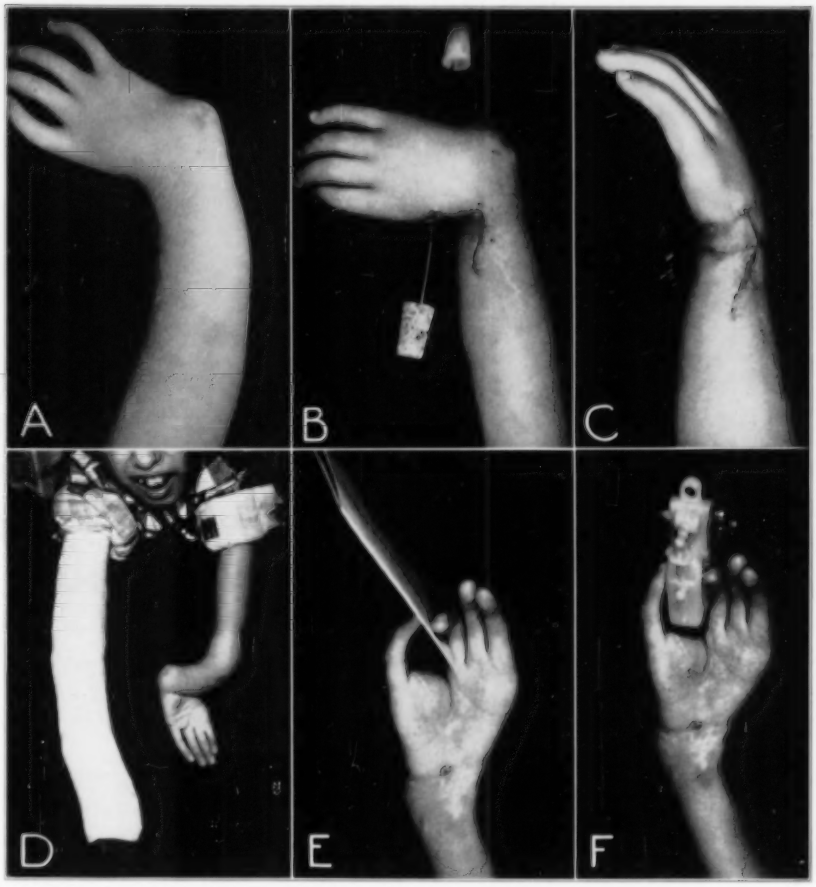

FIG. 5

Sequence of reconstructive procedures for total absence of the radial component.

Fig. 5, *A*: Appearance of the right hand before treatment in a three-year-old girl.

Fig. 5, *B*: Soft-tissue correction and tendon-lengthening to permit alignment of the hand with the forearm. Kirschner wire through the metacarpals permits application of light traction.

Fig. 5, *C*: Improved position of the hand after traction.

Fig. 5, *D*: Appearance of the right hand in plaster in a six-year-old boy, six weeks after autogenous fibular graft for stabilization of the hand. Compare the alignment of the right hand with the untreated left hand.

Fig. 5, *E*: Provision of pinch and grasp by pollicization of the little finger. Because of long-standing and severe deformity, rigidity of the index, long, and ring fingers made them unsuitable for the usual type of pollicization. Note the motion of pinching, one year after reconstruction.

Fig. 5, *F*: Same as *E*, showing grasping of larger objects. (Same patient as *D* and *E*.)

Pollicization of the index finger was considered to be the procedure of choice for providing the most useful thumb (Fig. 6). The neurovascular supply is preserved, and the index metacarpal is held in abducted position with the aid of a fresh autogenous-bone graft, fixing it to the third metacarpal and permitting good apposition with other fingers for pinch and grasp. The large web space created by shifting over of the index finger was covered by a pedicle flap from the infraclavicular area (Fig. 6, *B*). This site was generally preferred as a donor area for pedicle flaps; in girls, however, the lower abdominal area was used.

It was noted that in many cases of radial absence, the deformity was bilat-

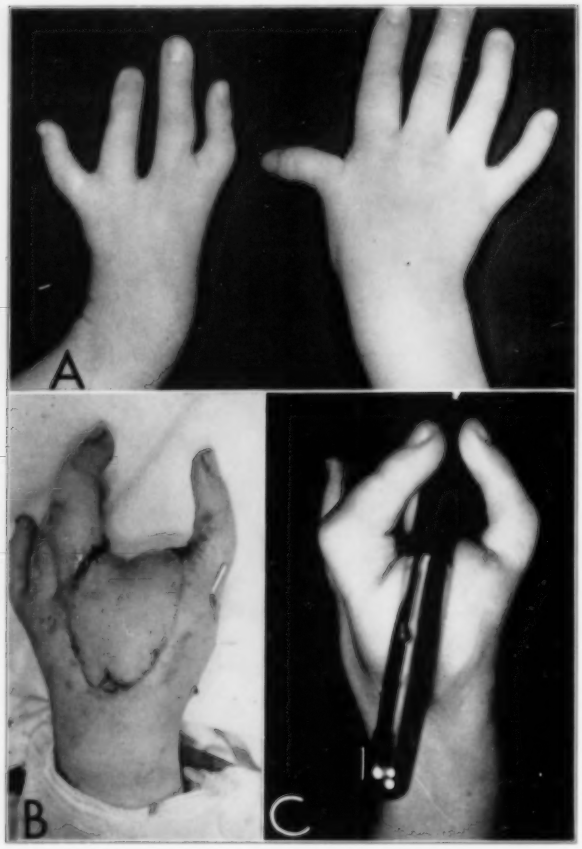

FIG. 6

Reconstruction of a missing thumb in an eight-year-old boy.

Fig. 6, *A*: Right hand shows severe hypoplasia of the thumb, absence of radial carpal bones, and no active motion, owing to absence of tendons. The left hand shows complete absence of the thumb ray and a bent little finger.

Fig. 6, *B*: Pollicization of the left index finger by means of rotation osteotomy of the base of the second metacarpal, bone graft between the second and third metacarpals, and abdominal pedicle to the second web space. The photograph was made four weeks after the beginning of reconstruction.

Fig. 6, *C*: Good pinching was attained, as shown in the photograph made one year after reconstruction.

eral and symmetrical. In three patients there was complete absence of the radial component on one side, whereas the other hand had no anomaly of the radial bone, but the thumb was vestigial, having only one or two phalanges and no bone connection to the rest of the hand. One of these thumbs had an attenuated extensor tendon, but in the others, no active motion was present. Such hypoplastic thumbs were considered to be related to anomalies of radial components, being the result of lesser penetrance; this concept applied even in cases of unilateral hypoplasia of the thumb (Fig. 3). These etiological considerations, even though interesting, did not materially alter the problem of reconstruction. By attaching pedicle flaps proximally to the vestigial thumb it was possible to give it length, and by connecting it by autogenous-bone graft to the second metacarpal, to give it stability, although the ultimate function was not so good as that of the pol-

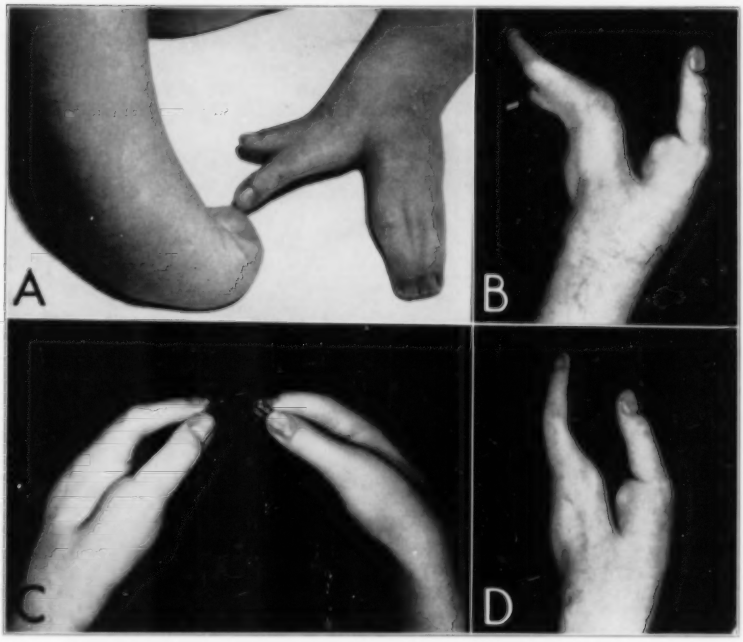

FIG. 7

Absence of the medial component.

Fig. 7, *A*: Absent medial component in the left hand, associated with webbing of the ulnar digits, in a three-year-old girl. There is complete absence of the right hand.

Fig. 7, *B*: Medial absence in the left hand of a six-year-old boy, complicated by dorsal subluxation of the metacarpophalangeal joints of the ulnar digits. Pinching and grasping were not possible.

Fig. 7, *C*: Appearance of the hand shown in *B*, six months after osteotomy at the base of the proximal phalanx of the ulnar digit. Note improved alignment and pinch.

Fig. 7, *D*: Same hand as *C*, showing corrected alignment after osteotomy.

licized index fingers. Moreover, a longer period of time and more operative steps were required. Consequently, it was found more practical to carry out pollicization of the index finger when the hypoplastic thumb was small and atrophic and had no metacarpals and no tendinous connection (Fig. 6, *A*).

Absence of the radius may be associated with multiple congenital abnormalities and hypoplastic anaemia (Fanconi's syndrome), which may be lethal [11]. This condition was not encountered in our group of patients.

Absence of the Medial Component

Anomalies of the medial component are referred to as cleft or lobster hand and may have the cleavage line through the middle finger, so that the thumb and index are separated from the ring and little fingers by a deep cleft. The cleft may extend through the carpus, and in some patients it is very wide. In the extreme form of this condition only two digits are present, one on the radial aspect and the other on the ulnar aspect of the hand (Fig. 7).

The patients develop an amazing dexterity, even though they may have only two digits bilaterally. Some of the patients in this study excel in typing and acrobatics, although no operative treatment was carried out. It was not considered practical to suture the cleft of the palm simply for appearance. Unless rotation osteotomy is done to oppose the fingers, suturing of the palmar cleft hampered pulp-to-pulp pinching. Reconstructive procedures were done on these digits only when deviation of their long axes developed owing to unequal growth or

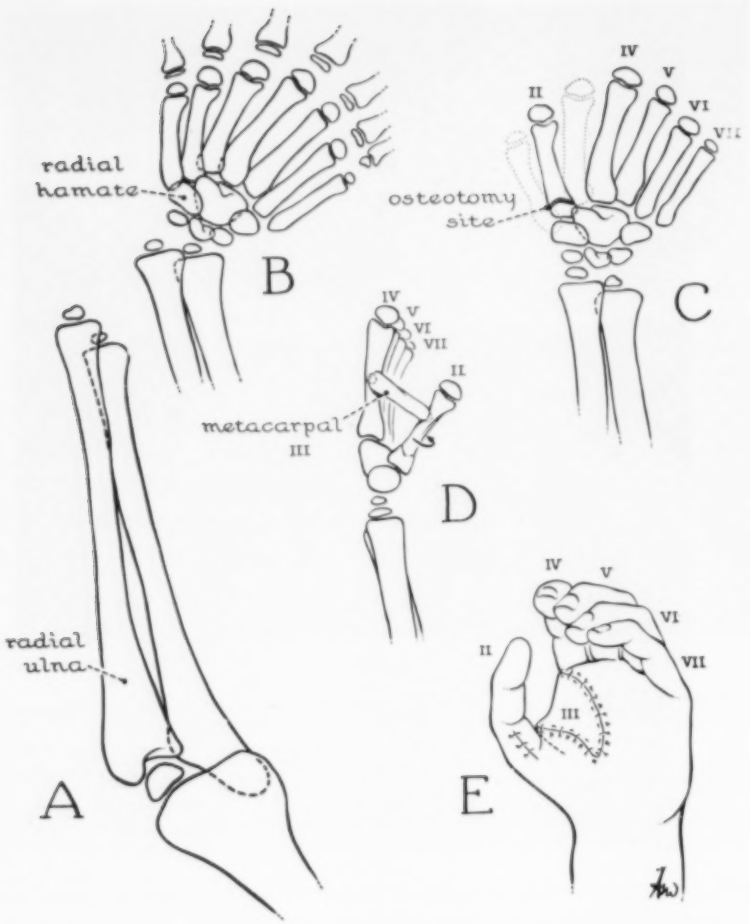

FIG. 8

Diagrammatic representation of ulnar duplication (mirror-hand).

Fig. 8, *A* and *B*: Duplication of the ulna and of the ulnar-carpal and ulnar-digital components. There is fusion of the two capitate and lunate bones.

Fig. 8, *C* and *D*: The method used to provide a pollicized digit to give pinch and grasp. The first and third digits were ablated; rotation osteotomy of the second digit was stabilized by a bone graft, using the metacarpal of the third digit.

Fig. 8, *E*: The space created by the pollicization of the second digit was covered by filleted skin of the third digit, acting as a flap. The fourth, fifth, sixth, and seventh digits were retained as the normal complement of fingers of the hand.

tendinous overpull. Usually, osteotomy was sufficient to correct alignment (Figs. 7, *B*; 7, *C*; and 7, *D*), but occasionally arthrodesis was required.

Absence of the Ulnar Component

Absence of the ulnar component, namely, the ulna and the three ulnar digits, is a rare condition. This abnormality did not occur in my series of cases.

Deformities and Abnormalities

The deformities of the upper extremities are divided into four categories on the basis of four regions: the shoulder girdle, upper arm, forearm, and hand and digits (Table I). There were four patients with deformities (two of which were

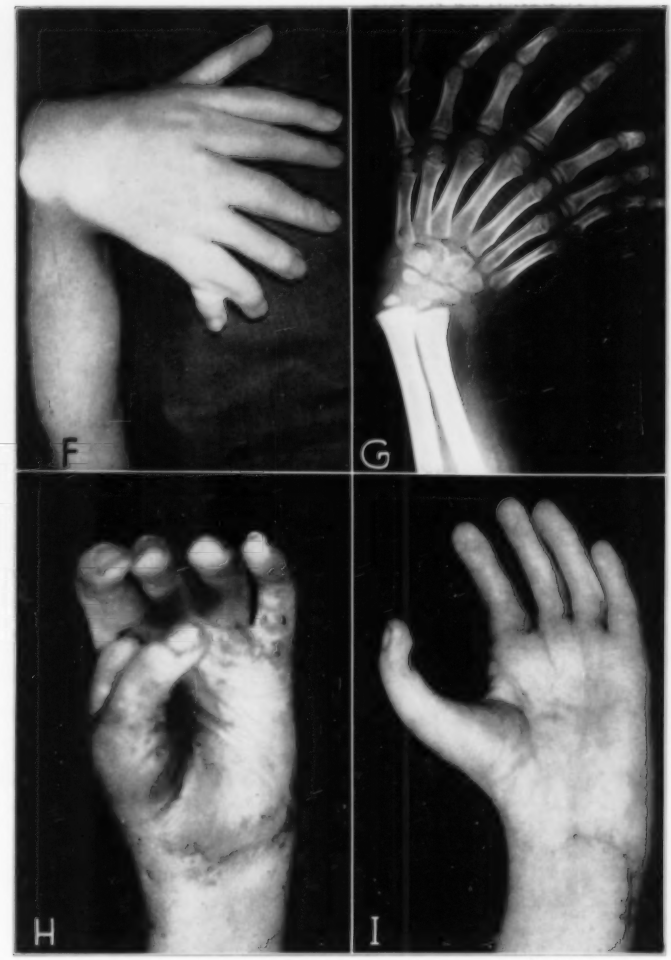

FIG. 8

Fig. 8, *F*: Photograph of the left hand of an eight-year-old boy, showing ulnar duplication, with seven digits.

Fig. 8, *G*: Roentgenogram of the hand shown in *F*.

Fig. 8, *H*: Appearance of the hand six weeks after reconstruction by the method illustrated in *C*, *D*, and *E*.

Fig. 8, *I*: Same hand as *H*, photographed six months after reconstruction and three weeks after muscle transfer of flexor carpi ulnaris to the common extensors of the digits, to improve extension of the digits.

bilateral) of the shoulder girdle. These patients had various anomalies of the upper part of the humerus and of the scapula that were usually associated with extensive abnormalities of the muscles, which were paralyzed or absent. One patient, a five-year-old girl, had a deformity of the left shoulder, as well as of the entire arm. This anomaly resembled Erb's paralysis clinically, although there was more extensive involvement of the muscles and a striking deformity of the hand. There were also anomalies of the upper epiphysis of the humerus and of the lower end of the radius combined with synostosis of the upper ends of the ulna and radius and distortion of the bones of the fingers. Muscle transfer to give flexion of the elbow and stabilization of the wrist have been deferred until the patient reaches ten years of age. The alignment of the hands and flexion

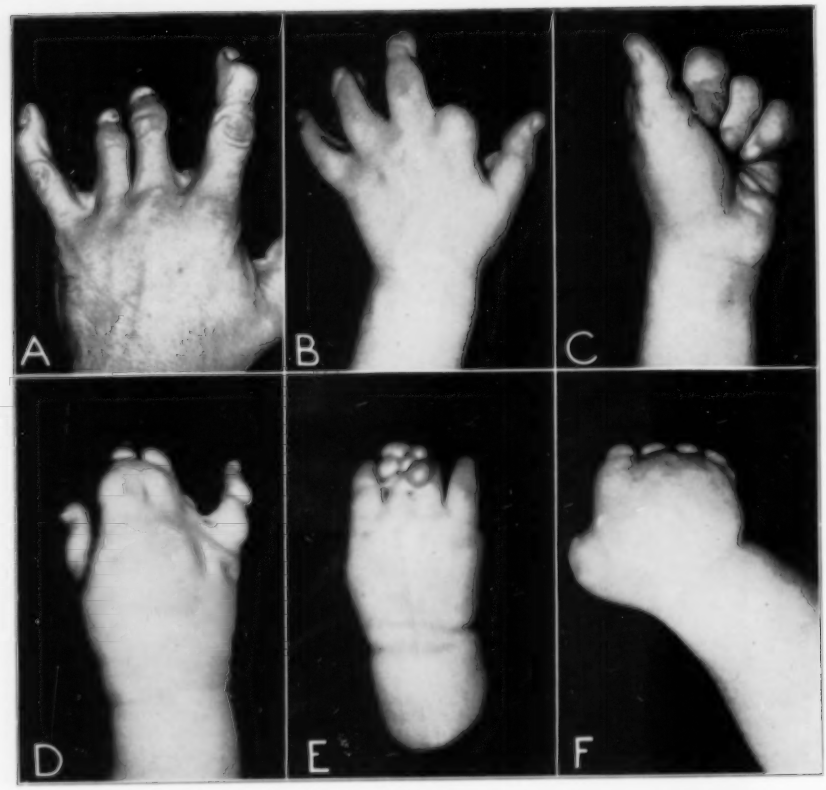

FIG. 9

Short or partially amputated digits (brachydactyly and ectrodactyly).

Fig. 9, *A*: Congenital shortness of the ring and long fingers of the left hand in an adult male. There was also fusion of the two proximal phalanges in the shortened fingers. (No handicap.)

Fig. 9, *B*: Absence of the index finger and shortening of the long and ring fingers of the right hand in a five-year-old girl. No nails were formed on the long and ring fingers.

Fig. 9, *C*: Same as *B*. No surgical treatment was required because pinch and grasp were adequate.

Fig. 9, *D*: Partial amputation of ring finger and shortness and webbing of the index and long fingers of the right hand in a two-year-old boy. Reconstruction involved separation of the long finger from the index and stump of the ring fingers. Adequate pinch and grasp were attained.

Fig. 9, *E*: Partial amputation of the long and ring fingers of the right hand, associated with a cluster of spherical skin structures, in a one-year-old boy. Separation of the fingers provided some grasp but poor pinch. The spherical appendages were discarded.

Fig. 9, *F*: Absence of the phalanges of all digits of the right hand in a three-year-old girl. Deepening of the first web and lengthening of the thumb with pedicle and bone strut provided some prehension, but no pinch.

of the elbow have been maintained with elastic splints.

Of the abnormalities involving the forearm, radio-ulnar fusion was the most common. One of these patients had bilateral hypoplasia of the radius and absence of the thumb (Fig. 3, *B*). In this patient, there was a radial deviation of both hands, and the reconstructive procedure entailed shortening of the ulnar shaft to give a more normal alignment of the hand with the long axis of the forearm. An alternative method is to divide the radius obliquely, just below the point of fusion. A sliding osteotomy of this type, along with partial section of the interosseous fascia, permits advancement of the radius distally and provides support to the carpus and the hand in a corrected position. No attempt was made to

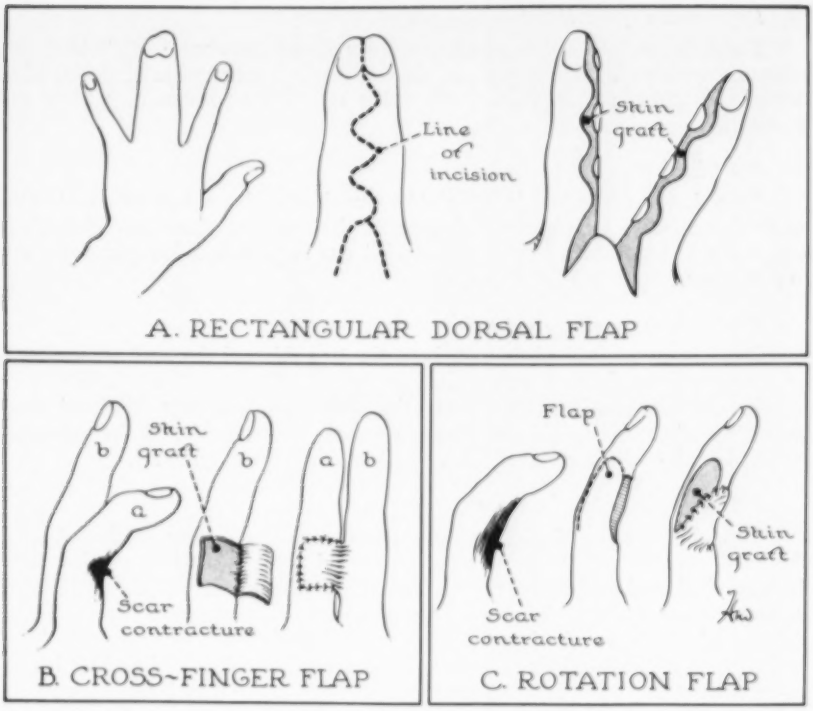

FIG. 10

Graphic illustration of the management of simple webbed fingers (syndactyly).

Fig. 10, *A*: A dorsal rectangular flap is used to form the floor of the webbed space between the fingers. The line of incision between the fingers is wavy to form V-shaped flaps of skin along the margin of the incision.

Fig. 10, *B*: Scar contractures frequently develop in association with webbed fingers and may be owing to slower growth of grafted skin, as compared with the normal tissue. Cross-finger flap brings the skin and subcutaneous tissue into the area of scar contracture.

Fig. 10, *C*: Local rotation flap from the lateral aspect of the finger brings normal supple skin with subcutaneous tissue into the area of scar contracture.

In *B* and *C*, the defects created by shifting of flaps have to be replaced by skin-grafting.

provide pronation and supination in any of the patients.

Duplication of the Ulna

Duplication of the ulnar component, referred to as mirror-hand, is an uncommon deformity of the forearm (Fig. 8). In addition to two complete ulnae, there is duplication of the carpal elements [17], and usually there are seven fingers (there are two ulnar complements of three fingers on either side of the central index finger). These patients have no pinch or grasp because none of the fingers can oppose one another. Reconstruction in the case illustrated was carried out when the patient was eight years old. The first and third digits were removed, and the second digit was shifted to function as a thumb. Rotation osteotomy was carried out at the base of the second metacarpal (Fig. 8, *D*), and the new thumb was held in position with a strut graft between the second and fourth metacarpals. The previously removed third metacarpal was used as the graft. The wide web created by pollicization of the second digit was covered by the filleted skin of the third digit, using it as a pedicle flap. The fourth, fifth, sixth, and seventh digits were retained as the normal component of the hand (Figs. 8, *C* and 8, *E*). This reconstructive procedure produced a hand of reasonably satisfactory appearance with efficient pinch and a strong grasp (Figs. 8, *H* and 8, *I*).

Deformities of the Hand and Digits

Forty anomalies in this group of twenty-six patients were subdivided into categories of bone fusions, bent digits, short or partially amputated fingers, webbed digits, and miscellaneous deformities, which included supernumerary parts and duplication.

Bone Fusion

Bone fusion of fingers is invariably complicated by the presence of other anomalies, such as webbing and absence of phalanges or of entire digits. Early separation of individual fingers was carried out to permit unhampered use and to encourage growth and development.

Bent Digits

Bent digits resulted when growth on the two sides of the digit was unequal or when portions of two fingers articulated with a single metacarpal. Correction of this deformity can be deferred until the patient reaches later childhood, when osteotomy of the shaft will usually give a satisfactory result. If the deformity recurred, fusion of the involved joint was found helpful (Fig. 6, *A*).

Partially Amputated Digits

Partially amputated digits may produce a rather bizarre configuration of the hand, especially if there are other associated anomalies. If reasonably satisfactory pinch and grasp are present, operative treatment may be deferred (Figs. 9, *A*; 9, *B*; and 9, *C*). If the thumb is short and the index finger is absent, the efficiency of pinch may be improved by deepening the cleft between the thumb and the rest of the hand by removing the intervening metacarpal and by lengthening the thumb with a bone strut (Fig. 9, *F*). When the thumb was absent, pollicization of the index finger, even if it was incomplete, gave useful pinch and grasp in most cases of this type.

As was mentioned earlier, reconstruction of absent digits involves numerous operative steps and does not produce entirely satisfactory results. The requirements for success are the construction of movable digits that have good sensation and can oppose each other for pinch and grasp. Lengthening of the stump of the hand by a distant pedicle and bone strut provides rigid parts, but unless one of them is articulated, useful prehension is not possible. This procedure was carried out in three patients whose fingers were absent. In two with first metacarpal bones, useful pinch was attained by lengthening of the thumb stump and by tendon transfer to provide opposition.

Toe transfer provides finger-like members with nails and an articulating bone framework. Several toes can be shifted to the hand in stages, supplying several digits when these are absent in the hand [7]. In two of our patients, this procedure was chosen to replace absent digits. In one case, an attempt was made to transfer the third and fourth toes to the central portion of the carpus to act as fingers and to oppose the first metacarpal—the only digit present in the hand before reconstruction. An accidental complication of anaesthesia occurred during one of the phases of reconstruction, and separation of the hand from the foot was imperative for the general management of the child. This premature separation resulted in the loss of the distal phalanx of one of the transferred toes and may have contributed to the stiffness of the joint of the other toe. Although the wrist movers were utilized as motors to the transferred toes, only limited prehension was attained, the pinch being ineffective. In another patient without fingers, who had a short thumb without a distal phalanx, a transfer of two phalanges of the third toe was carried out to the capitate bone of the carpus. This procedure provided a movable finger with useful sensation and permitted pinching action against the foreshortened thumb, but no true grasp. This limited experience does not permit generalization about toe transfer as a method of reconstruction of absent

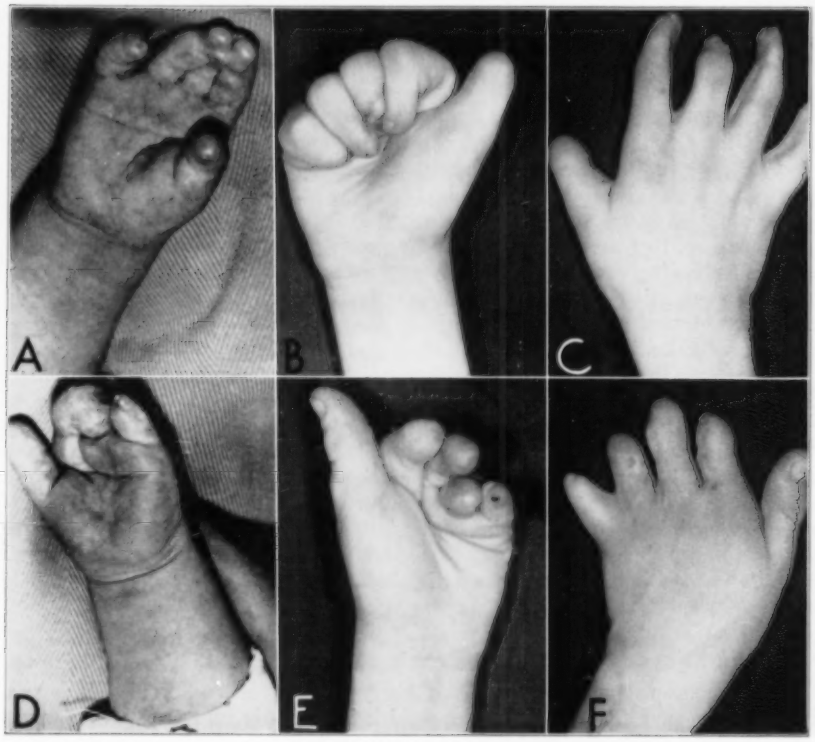

FIG. 11

Webbed digits (syndactyly).

Fig. 11, *A*: Right hand of a three-year-old boy, showing webbing of digits, complicated by shortness and bone fusion. The thumb lacks a distal phalanx.

Fig. 11, *B*: Reconstruction was carried out in several stages. The photograph was made at seven years of age and shows adequate flexion.

Fig. 11, *C*: Same as *B*, showing extension of the fingers.

Fig. 11, *D*: Left hand of the same patient as shown in *A*. The deformity here was more severe, distal phalanges being absent in all fingers.

Fig. 11, *E*: Same hand as in *D*, photographed at seven years of age, at the completion of reconstruction. Flexion was limited, but pinch and grasp were adequate. Despite this deformity, with the aid of reconstruction, this boy attained good function of the hand.

Fig. 11, *F*: Same hand as in *E*, showing extension of the fingers.

Despite these severe deformities of both hands, the boy is not handicapped in either school or at home, because, with the aid of surgical correction, he developed satisfactory manual dexterity.

digits in the hand. This deformity still remains one of the most difficult ones to correct.

Webbed Digits (Syndactylism)

Webbing of digits often occurs sporadically, although sometimes a clear-cut pattern of inheritance is evident. Although this condition is said to occur more frequently in males, it was equally distributed among the sexes in my group of fourteen cases, half of the total being bilateral. Webbing of fingers varies in severity from a mild anomaly, such as unusually long web folds, to a severe one, in which all fingers are involved. Some of the conditions with which webbing is associated are bone fusions, bands, absent phalanges, bifid digits, and cleft hand (Fig. 7, *A;* 9, *D;* and 9, *E*).

In cutaneous webbing, which is usually symmetrical and familial, the third

and fourth fingers are most commonly joined together. Our most satisfactory results have been obtained when operative correction was performed fairly early (before the patient was two years of age). In this procedure a rectangular, dorsally based pedicle flap is used to form the floor of the web space between fingers, V-shaped flaps are formed along the margins of the skin defect, and then thick-split or full-thickness skin grafts are used to cover the defect (Fig. 10, *A*). In moderately severe and severe deformities, secondary involvements of ligaments may occur if the uncorrected condition is of long standing. Even if full-thickness grafts are used in reconstruction, the growth of grafts may be slower than that of the surrounding normal tissues. In my group of cases, several operative procedures, extending over several years, were usually required to maintain correction. Local rotation flaps and cross-finger flaps were found to be useful for the correction of recurring flexion contracture associated with extensive webbing involving several adjacent digits (Figs. 10, *B* and 10, *C*).

If osseous fusion is associated with webbing, the terminal phalanges are most frequently involved; all four fingers may be joined together, forming a so-called mitten hand (Fig. 11). In patients with such deformities, the separation of individual fingers should be carried out as soon as it is practical after the patient's first year. Unless the hand is used for prehension, its development will be delayed. In webbing complicated by congenital bands (annular grooves), bone fusions or partial absence of digits, several concurrent reconstructive procedures were employed, but the likelihood of the recurrence of some anomaly requiring operative correction was even greater in these patients than in those with simple cutaneous webbing (Fig. 11).

Duplication and Supernumerary Parts

Some authors [21] have proposed the theory that a single embryonic bud has an inherent tendency toward duplication, which is normally repressed. Other workers believe that even the occurrence of supernumerary fingers is an expression of duplication of the limb. Experimentally, duplications of an extremity have been produced by transplantation of limbs in early embryos [22]. Two types of duplication were seen in our group of patients: one type had a duplication of a particular digit through some of its length, both articulating with a single metacarpal; the other type had a completely formed digit, including carpal bones. Both were usually corrected for cosmetic reasons. In bifid digits, it was occasionally difficult to decide which portion to discard if both had complete attachment to the tendons; usually the member giving the best alignment was retained.

General Affections and Neuromuscular Disturbances

These subdivisions are based on the classification outlined by Fairbank [10], but their general arrangement has been modified by the inclusion of other pertinent systemic disturbances [15] as well as the various neuromuscular conditions which affect the upper extremities [18]. The list of conditions given here is not comprehensive, since some of the patients with anomalies of the upper limb who would have been classified in this group did not seek treatment and thus were not included.

The discussion of these interesting systemic disturbances (Table II) is beyond the scope of this paper. Of the fifty-nine patients included in this group, sixteen had some disturbances of bone growth or of deformities of joints and ligaments and forty-three had some disturbances of the neuromuscular system such as arthrogryposis, cerebral palsy, and the like. The deformities and abnormalities of the different parts of the upper extremity, associated with the various subdivisions included in Table II, were frequently similar to those outlined in Table I. The management of these deformities was similar to that outlined previously, and consequently no further comment is required.

DISCUSSION

The foregoing discussion of the various deformities and the methods used for their correction emphasizes the great complexities of many of these reconstructive problems. It would be ideal to restore the nearly normal appearance and function of the hand in correction of congenital deformities of the upper extremity; however, it is more practical to strive for usual function of the hand, namely, good sensation and satisfactory pinch and grasp. These should be the goals of reconstruction. If useful function is present, no part of it should be sacrificed to gain a more normal appearance. The minimal number of surgical procedures that will attain the relatively greatest function should be selected. The more operative procedures performed, the more extensive is the formation of scar. Excessive scar formation may even negate all the benefits of the reconstructive procedures.

Even if successful reconstruction is carried out in the patient's early years, constant observation is required during the growth period for early detection of the recurrence of the deformity. Such recurrences are usual and are owing to persistence of an inherent muscle imbalance or to unequal growth of the various parts.

Certain types of deformities have in the past defied reconstructive ingenuity, but new procedures developed in recent years permit extension of these techniques in the field of congenital abnormalities. Transfer of joints by free transplantation from the foot offers a practical method of providing movable parts [8]. Reconstructions requiring the use of distal pedicle flaps with poor sensation can be improved by a subsequent transfer of a neurovascular island flap [6]. This procedure would provide an island of normal perception in the strategically important area.

The foregoing discussion emphasizes that reconstruction of congenital abnormalities is not for the meek, impatient, or easily discouraged surgeon. Most of these conditions cannot be corrected by a single surgical maneuver, however brilliantly executed. Indeed, because of the dynamic status of the deformity with continuous alterations during growth, constant vigilance is required on the part of the surgeon to forestall a recurrence or the development of a new derangement. In addition, long and painstaking hours of re-education on the part of the patient and the members of the rehabilitation team are required before useful function of the reconstructed member is attained. Frequently, the ultimate success is predicated upon the ability of the surgeon to create in a young patient the desire to gain the objective. The accomplishment of this is, in itself, a great feat.

SUMMARY AND CONCLUSION

Congenital abnormalities of the upper extremities may be hereditary or acquired *in utero*. They may be unilateral or may affect both limbs with identical or different deformities.

The abnormalities in 120 patients have been reviewed and classified into two main groups: those anomalies of the upper extremity only and those associated with some general systemic disturbance. In order to crystallize the reconstructive need, the sixty-one patients in the first group were classified on the basis of clinical and anatomical manifestations.

The primary aim of reconstruction is to provide the basic functions of the limb, namely, good skin and sensation, the ability to place the hand in a strategically useful position, and satisfactory pinch and grasp. These basic needs should be provided with the least possible number of surgical procedures. The procedures employed were stabilization and bone support, phalangization of fused digits by shifting local and distant skin, transfer of digits to provide pinch and grasp, and muscle transfer to give motion to newly constructed parts.

The specific procedures used in a few selected patients are described to illustrate the individual needs of each patient and to stress the complexities of these reconstructive procedures.

Deformities of the radial component constituted the largest group of the anomalies of the forearm. The most severe type of this deformity required stabilization of the hand by a fibular graft and pollicization of the index finger to replace the absent thumb and provide prehension.

Reconstruction of missing digits is one of the more difficult problems and entails the transfer of skin pedicles and bone struts or the transplantation of one or more toes. Both methods have their limitations and neither has restored normal function to the deformed hand.

Other abnormalities such as fused, webbed, or partially amputated digits, and supernumerary digits, require phalangization, local and distal skin transfer, and other procedures.

The general affections were in a group of fifty-nine patients, in whom the deformity of the upper extremity was owing to a systemic disturbance or was associated with it. Some of these deformities were similar in configuration to the anomalies of the first group and required similar management.

Because of the dynamic character of these deformities inherent in the process of growth, recurrences of the deformity may take place even after successful reconstruction, and therefore constant vigilance is required.

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DISCUSSION

Dr. Arthur J. Barsky, New York, N. Y.: For thumb replacement or substitution, we believe that the migration of a digit on a neurovascular pedicle is preferable to the pollicization procedure, which involves the use of an abdominal pedicle and requires several stages. The use of a neurovascular pedicle is, I believe, a good deal simpler and has the advantage of being a one-stage procedure which yields results that are functionally and aesthetically satisfactory.

Both in thumb hypoplasia and in the so-called floating thumb, the level of the metacarpophalangeal joint of the thumb is much too far distal, generally at the level of the metacarpophalangeal joints of the other fingers. In the floating thumb, with its deficient or absent metacarpal, we are now first moving the digit on a neurovascular pedicle to the region of the thenar eminence, and then at a second stage doing a free transplant, from the toe, of a metatarsophalangeal joint. The proximal end of the tarsal bone is mortised into the adjacent metacarpal, and a lap joint performed on the opposite end. Subsequently, tendon transfers into the finger are carried out. It is much too early to state that complete growth and development will take place, but at the present time we feel encouraged to continue along these lines.

In cases of ectrodactyly, where the fingers are clumped and many of the distal phalanges are missing, if spherical nubbins of tissue are present, we are trying to transplant these nubbins to the tips of the fingers when the digits are separated, to give added length. Just how much sensation these tips will finally have, I cannot say at this time, for our patients are all much too young to give us reliable responses.

In syndactyly, we advise locating the digital nerve immediately after the palmar incision has been made and tracing its course. Sometimes we find, instead of two normal branches, one major trunk will run along the border of one finger and bifurcate much more distally than one would expect. The nerve should then be split back so as to provide innervation for the adjacent side of the other finger. This same approach should be used in ablating a polydactylous digit, especially when it is on the thumb side.

The radial club-hand is an extremely difficult condition to treat. To begin with, I feel that the forearm is shortened and that no matter what one does, it will still be short. Furthermore, the surgeon is on the horns of a dilemma. On the one hand, early operation will prevent the bowing of the ulna but, on the other hand, operative procedures which might possibly interfere with growth and development, although they might straighten the hand, cannot be used. Some say that nothing should be done in these cases, since many of these patients, if they have thumbs, have amazingly good function. However, I do feel that if function and appearance can be improved by surgery, one is justified in proceeding.

Transplantation of the upper end of the fibula as a strut certainly seems to hold forth some promise. Several years ago, Dr. Riordan presented a very fine paper on this subject, and if he is here, perhaps he could tell us if the transplanted epiphyses have continued to grow.

Dr. Daniel C. Riordan, New Orleans, Louisiana: I think I am one of those he referred to when he said, "Operate on these early." My reason is that I think the habit pattern that these children develop is what makes us have poor results. You might have a beautiful reconstruction of some abnormality, such as the absence of a thumb, and yet the patient will not use it in the new position. I think one of the reasons is that we have waited until too late and they have a fixed pattern and cannot change. If you get them at six months and there is no physical reason for not operating, I think we can get a better functional result.

I would like to offer one suggestion in the patient that had amputation of all extremities. I think there is a real place in these congenital amputations where you have no hand on either side and you have an arm that is long enough for biceps transplantation, which gives them some real means of getting a form of sensation which you cannot get by any other means.

Thrombofibrosis of the Ulnar Artery in the Palm

BY DANIEL G. COSTIGAN, M.D., JAMES M. RILEY, JR., M.D., AND FRED E. COY, JR., M.D.,
LOUISVILLE, KENTUCKY

Jackson, von Rosen, and Teece each described an occurrence of thrombofibrosis of the ulnar artery, an entity we encountered twice in the past five years. Since this condition is rarely reported, we consider the addition of two cases to the literature of interest.

The ulnar artery at the wrist lies beneath the volar carpal ligament and immediately lateral to the ulnar nerve. More distally, after emerging from beneath the volar carpal ligament, the artery courses laterally to the pisiform and superficially to the transverse carpal ligament (Fig. 1). In this area the ulnar artery is superficial, covered only by skin, subcutaneous fat, palmaris brevis, and palmar fascia. The artery in this superficial location is vulnerable to injury.

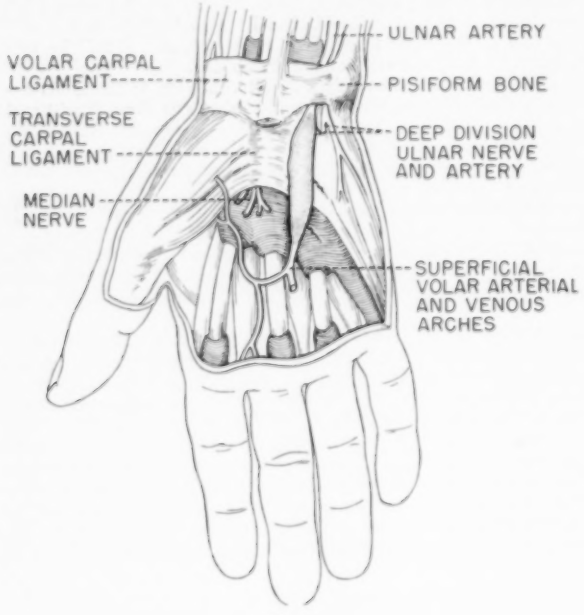

FIG. 1

Schematic drawing of the anatomy of the ulnar artery in the palm showing it fibrosed and cordlike as seen in Cases 1 and 2.

Trauma appears to be the cause of thrombosis with subsequent fibrosis of the artery. In each of our patients, there was a history of trauma to account for contusion of the artery. According to von Rosen, if the media of the artery wall is injured an aneurysm is likely to result; whereas, if the intima is damaged thrombosis will occur. Organization of the thrombosis results in fibrosis of the artery with the development of a fibrotic cordlike structure with no lumen. The microscopic reports were similar and showed proliferation of fibrous tissue, old hemorrhage, and dense collagenous tissue (Fig. 2).

FIG. 2

Photomicrograph of Case 2 showing the wall of the ulnar artery with the thrombosis undergoing fibrotic changes.

Treatment consisted in the excision of the fibrosed vessel in the following manner. The ulnar artery is approached by an S-shaped incision following the skin lines on the volar and ulnar sides of the hand and wrist. The artery can be seen lateral to the nerve immediately beneath the skin and subcutaneous tissue after the palmaris brevis and palmar fascia are incised and retracted medially. The cordlike structure of the artery is readily recognizable. After dissection, a segment of the artery is resected. Surgery is done under tourniquet control and after resection of the artery, the tourniquet is released and bleeding is controlled. Postoperative dressing includes a cock-up plaster splint.

CASE 1. A. C. R., a man, thirty-nine years old, injured his hand when he attempted to break loose a frozen lock three months before examination. He had had immediate pain on the ulnar border of the wrist and in the hypothenar eminence. The pain had persisted and increased. Examination was entirely negative with the exception of tenderness in the hypothenar eminence and just proximal to this at the wrist. No vascular changes were noted, nor was there any paraesthesia of the ring and little fingers. The hand was explored and a fibrosed ulnar artery found. Approximately two inches of the artery was resected. When he awoke from anaesthesia the patient was without pain and has remained asymptomatic for six years.

CASE 2. O. C., a man, thirty-six years old, was seen after he injured his right hand by striking the hypothenar eminence against a jammed window frame. He had immediate severe pain which gradually increased until he was unable to sleep. He also complained of numbness of the little finger and ulnar half of the ring finger of three days' duration. The man was a mechanic and said that he was unable to use a wrench. Examination revealed that

the right hypothenar eminence was slightly enlarged as compared with the same area in the left hand. There was point tenderness over the most prominent portion of the hypothenar eminence. Compression of the blood supply at the radial or ulnar arteries or obliterating the venous flow did not affect the pain. For three weeks steroids, vasodilators, and physical therapy failed to give relief; in fact, the pain became worse. Because of the previous experience in Case 1, a preoperative diagnosis was made of thrombosis of the ulnar artery. Seven and one-half weeks after the injury the hand was explored and the ulnar artery found to be thrombosed and fibrosed (Figs. 1 and 2). Approximately one and one-half inches of the artery was resected. When he awoke from anaesthesia this patient was also completely asymptomatic and has remained so for the past two years. We feel that ulnar neuritis in this patient was due to irritation from the thrombosed vessel rather than to direct injury to the nerve itself since neuritis did not develop for several days.

SUMMARY

The most prominent feature in both cases of thrombofibrosis of the ulnar artery was the single traumatic incident followed by immediate, persistent, and severe pain. Pain was completely and permanently relieved by surgery. In neither patient was there evidence of injury to the deep branch of the ulnar nerve nor was there evidence of pre-existing vascular disease.

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Arthroplasty of the Hip in Rheumatoid Arthritis

A Follow-up Study of Sixty-eight Hips*

BY J. R. SCHWARTZMANN, M.D., TUCSON, ARIZONA

Experiences reported in orthopaedic literature relating to arthroplasty of the hip in rheumatoid arthritis indicate that the end results following surgery are generally discouraging. There is, in fact, uniformly little enthusiasm for arthroplasty of the hip in rheumatoid arthritis.

Many persons with rheumatoid arthritis have migrated to the southwestern part of the United States for whatever real or imagined benefit the climate may offer them. Even with the widespread use of new drugs in the symptomatic treatment of rheumatoid arthritis, this geographical area continues to attract relatively large numbers of arthritic patients. A significant number of patients thus have been available for the present study. In recent years, the control of disabling, generalized pain in rheumatoid arthritis by ACTH, cortisone, and similar medications has encouraged the arthritic patient to seek mechanical or surgical help to aid in accomplishing physical rehabilitation.

The patient with rheumatoid arthritis who has severe and generalized disease is disabled, more often than not, to the point of total invalidism. He presents economic, social, and psychological problems of considerable magnitude. In many patients in this series, there was a major economic problem, sometimes affecting the family. One, two, or more persons are frequently required to devote full time to the daily care of the severe arthritic cripple. An otherwise productive member of the family thus loses earning capacity.

Socially, the afflicted individual is unable to care for his own personal needs: toilet, feeding, dressing, or walking. In some instances personal hygiene, such as monthly hygiene in women or anal and perineal skin care, presents serious problems.

With the prospects of becoming a progressive economic and social liability to himself and to his family, the patient with severe arthritis may become a serious psychiatric problem. Three patients in this series made suicidal attempts at some time before arthroplasty.

Thus, to the severely disabled arthritic patient the ability to care for his personal needs and to move and walk, even a limited amount, becomes an extremely desirable goal to attain by either non-surgical or surgical means.

Considering these factors, it became the author's opinion that if the amount of constant care required for these patients could be reduced, if their pain could be relieved, if their deformities could be corrected, and if their hip function could be restored sufficiently to allow some degree of self-sufficiency, then a major surgical procedure was justified.

MATERIAL

In most patients multiple-joint involvement complicates the problem of mobilizing the hip joint. In this series forty-eight arthritic patients were studied. None of the forty-eight had isolated hip-joint disease, and nineteen had severe, generalized arthritis of the peripheral joints. In addition to peripheral-joint involvement, sixteen patients had severe spondylitis, however, six did not have spondylitis. With respect to the lower limbs, two patients had no involvement of either the knees or ankles. There were thirteen who had extensive, severe involvement of the

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FIG. 1-A

Preoperative roentgenogram showing complete ankylosis of one hip in poor functional position and fibrous ankylosis of the opposite hip which was painful and had springy motion. Preoperatively, there was no motion or pain in the left hip. The right hip had 30 degrees of flexion, 10 degrees of internal and external rotation, 180 degrees of extension, and no adduction or abduction.

knees and ankles in addition to the hip. Flexion deformities of the knees, equinovarus deformities of the feet, and torsion deformities of the long bones required correction in several patients before maximum rehabilitation by hip surgery could be realized.

Of the major weight-bearing joints in the lower limbs, the hip is most amenable to satisfactory arthroplasty. This report presents the results of arthroplasty of sixty-eight hips in forty-eight patients with rheumatoid arthritis.

Eight of the forty-eight patients in this series have had active rheumatoid disease for less than ten years; the remaining have had the disease for ten years or more. In this series the right and left hip were involved approximately the same number of times. Twenty patients had bilateral surgical procedures; twenty-eight, unilateral operations. Twenty-five of the sixty-eight hips operated upon had no preoperative motion in the joint due to either bony or fibrous ankylosis.

The youngest patient operated on was twelve years old, the oldest, sixty-two. The average age of all patients at the time of surgery was thirty-five years.

The extent of the hip disease in this series can be classified into three general groups:

1. Complete bony ankylosis with the hip in a poor functional position but more or less free of pain.

2. Fibrous ankylosis with only springy motion which was not measurable, a joint that appeared disorganized according to roentgenographic appearance and pain of disabling severity. (Figs. 1-A and 1-B).

3. Incomplete but progressive joint destruction, with varying degrees of motion present, and extreme pain becoming progressively more disabling. Preoperatively, twenty-five of the sixty-eight hips had no demonstrable motion. It has been noted during surgery with the patient anaesthetized that hips which were otherwise stiff could be made to show a fair degree of free motion once pain and

FIG. 1-B

When the postoperative roentgenogram was made, the left hip had 180 degrees of extension, 65 degrees of flexion toward a right angle, 20 degrees of abduction, 30 degrees of adduction, 10 degrees of internal rotation, and 20 degrees of external rotation. Preoperatively, the patient walked with crutches; postoperatively, no crutches were needed. Two and one-half years after surgery, there was no complaint of pain in the hip operated upon. Motion in the right hip increased to 75 degrees of flexion toward a right angle and 10 degrees of abduction and adduction after surgery on the left hip. Postoperatively, the patient can sit in a slightly elevated chair and teaches school regularly.

spasm were relieved by the anaesthesia. In two instances in this series, patients each with two apparently stiff hips could, after surgical reconstruction of one painful hip, mobilize the opposite hip to a useful degree. As yet, these two patients have not required arthroplasty of the second hip to establish useful function.

A disabling degree of preoperative pain in the hip exposed to arthroplasty was noted in thirty-eight hips, a moderate degree in ten, and not at all or only to a minimal degree in twenty of the sixty hips operated on. Fifteen of the forty-eight patients treated were unable to walk preoperatively. Only two of the forty-eight were able to walk without some aid. In this respect, it is interesting to report the status of some of the more severely involved non-ambulatory or slightly ambulatory patients. They could easily be compared to a straight stick or to a chair, depending on the position of ankylosis of the joints. They were unable to change a fixed position of deformity because of the ankylosis. Some of these people if they were placed against a wall in a leaning position were helpless to move.

Rheumatoid arthritis is a disease of soft tissue as well as of joints. Progressive changes in tendons, capsules, muscles, and skin result in fibrous hardening, thickening, and loss of normal elasticity and mobility. These changes add to the difficulty of mobilizing a stiff joint. Prolonged dysfunction of a joint resulted, in many instances, not only in the soft-tissue changes just described but also in inability of the patient to voluntarily contract the muscles which are normally needed to move the affected joint. There appeared to be so-called alienation of the muscles effecting this loss of voluntary contracture.

Prolonged disease of the skeletal structures, abetted by long-standing intra-

FIG. 2-A

View of the left hip as it appeared nine years after arthroplasty. The cup was eroding through the femoral shaft. The hip had no motion; it was springy, painful, and fixed in extension. The patient walked with two canes, sat obliquely across a chair, and worked regularly in an office.

articular and periarticular inflammatory disease, inevitably results in varying degrees of osteomalacia or osteoporosis. The extreme demineralization encountered frequently caused technical difficulties in performing arthroplasty.

SELECTION OF PATIENTS AND PREOPERATIVE REQUIREMENTS

Early in this series, only those patients who were extremely and totally disabled were selected for arthroplasty since it was the desire of the author to at least cause no additional disability to the patient in the event that surgery should fail to accomplish a useful degree of improvement. However, evaluation of the cases, as time passed, indicated that appreciable gain in function was being accomplished. As a result, elective arthroplasty has been recently recommended for less disabled patients with a view to avoiding technical problems during surgery, while, at the same time, saving or maintaining function which would otherwise have been lost. In this way a more satisfactory degree of rehabilitation was achieved.

All the patients operated upon in this series have met the following requirements:

1. Disability and symptoms which were not controlled by conservative treatment for a period of six months or more must be present.

2. Preoperative ability to contract the muscles which cross the major joints of the lower limbs to allow progressive strengthening and power regardless of pain and presence or absence of motion must be present. A patient who can exercise with pain and loss of motion and function and gains power and coordinated use of muscles by doing this is sufficiently assertive to cooperate well during postoperative rehabilitation.

3. There must have been controlled and balanced medication—steroids, ACTH, cortisone, or gold—before surgery.

4. A long life expectancy and good state of health are necessary to justify such a prolonged rehabilitative program.

5. The patient should have an acceptable mental and psychological attitude toward pain tolerance and exercises and have a positive desire for rehabilitation.

FIG. 2-B

Postoperatively, following revision of the hip cup, flexion was 45 degrees; extension, 180 degrees; abduction, 30 degrees; adduction, 20 degrees; and internal and external rotation, 20 degrees. At follow-up evaluation four years postoperatively, the patient had no pain but sometimes used one cane for walking; he sat well enough to be able to drive a car to work.

The degree of arthritis, indicated by pain, swelling, and elevated sedimentation rate, was not considered in the selection of patients. Patients with both active and inactive arthritis have had arthroplasty with no influence on the end result noted. In no instance has elective arthroplasty resulted in generalized acute exacerbation of the arthritic process.

OPERATIVE PROCEDURE

Detailed operative technique is not within the scope of this paper. In this series, I elected to use the classic Smith-Petersen Vitallium cup and the Naden-Reith prosthetic appliance. Technical problems were encountered at time of surgery, and in some instances completely altered the planned reconstructive approach.

Residual effects of previous surgical procedures such as arthroplasty, obturator neurectomy, and muscle transplants of the femoral neck, done for reconstructive or pain-relieving measures, were noted. The greatest technical difficulty encountered was a Smith-Petersen cup which had virtually cut through the upper part of the femoral shaft destroying much bone needed for the arthroplasty. One such problem and the operative correction is demonstrated in Figures 2-A and 2-B. Scarring with loss of cleavage planes and obscuring of surgical landmarks needed for ease of exposure were encountered in the other hips which had been previously operated upon.

Osteomalacia which in may instances was extreme, either generalized or localized, was the greatest surgical problem. Eggshell-thin cortex of the femoral neck and trochanter offered little or no stable substance for holding either a prosthesis or cup. Frequently, apparently good bone structure in the head of the femur had to be discarded because of extreme cystic atrophy of the neck with loss of supportive bone structures. In general, the principle of establishing a uniform bone base to support the implant used for arthroplasty was followed. I believe that failure to recognize underlying weak spots in the femoral head and neck during arthroplasty may explain frequent collapse of the femoral head and neck postoperatively when weight-bearing is started.

Soft-tissue structures presented technical problems during surgery in many in-

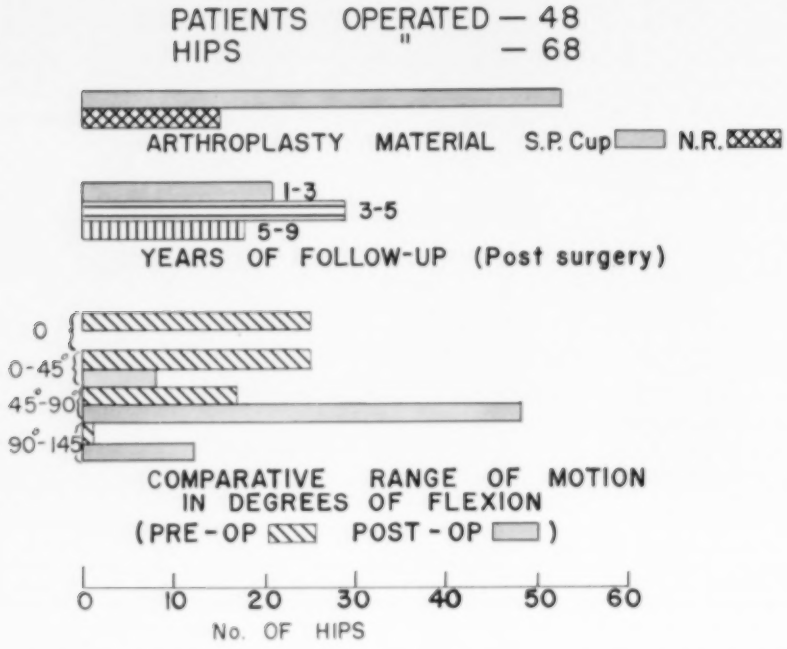

CHART I

stances. Hard, rigid fibrosis and contracture of muscle, tendon, fascia, and capsule required tenotomy of adductors, lengthening of hip flexors, and recession of abductors, as well as fasciectomy before the joint could be mobilized and the wound closed. In hips with long-standing ankylosis the muscles crossing the joint were of poor vitality, a finding which emphasizes the need for rigid discipline and a standard exercise program for preoperative and postoperative muscle education and re-education. In one instance, calcification in the substance of the glutaeus maximus required lengthening of this muscle before flexion of the hip was possible.

The problems just enumerated required alteration of the reconstructive procedure according to the material at hand in order to accomplish the reconstruction.

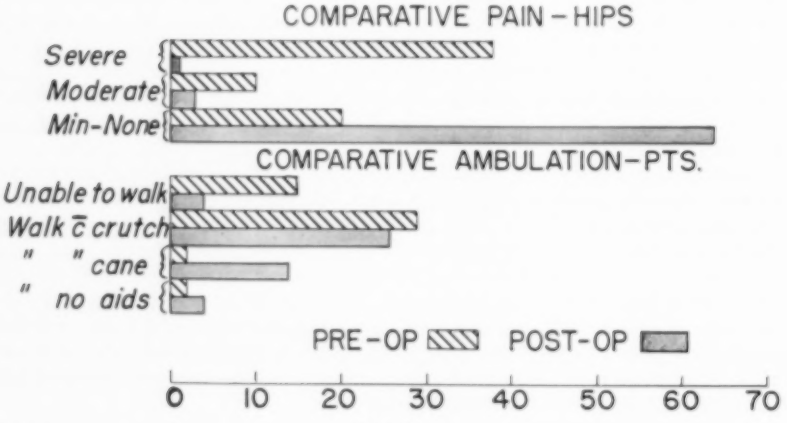

CHART II

POSTOPERATIVE CARE

Standard principles again were observed for postoperative care. Balanced suspension with adhesive skin traction holding the leg in abduction, 175 degrees extension, and 15 degrees internal rotation was maintained continuously for from eighteen to twenty-one days after operation, at which time traction was removed and active mobilization with passive assisted motion begun. By the end of the fourth postoperative week, alternate crutch-walking was added to the daily exercise program and, when possible, bicycling exercises started. Throughout a minimum of a year, daily muscle-strengthening exercises and active and passive mobilizing exercises were pursued. Crutch-walking is required for a minimum of six to eight months postoperatively. Depending on the ability of the patient and the amount of arthritis in other joints, the patient is allowed to discard or continue using crutches or a cane. When both hips were operated on, an arbitrary period was established of at least four months between surgical reconstruction of each hip. I required this for two reasons. First, it enables the patient to concentrate on early rehabilitation of the hip first operated on; and second, if the first operative procedure failed, this waiting period gives the surgeon a better chance of re-evaluating the patient and deciding whether to operate on the second hip.

END RESULTS

Forty-eight patients who had sixty-eight arthroplasties have been analyzed in this series; twenty patients had bilateral procedures. A Smith-Petersen cup was inserted in fifty-three hips and a Naden-Reith hip prosthesis in fifteen. Postoperative follow-up period ranged from one year to nine years (Chart I).

Hip motion: Flexion and extension are the most important motions in sitting, standing, and walking. A comparison of preoperative and postoperative motion in flexion is shown in Chart I.

There were no hips that did not have increased flexion postoperatively; only eight hips were unable to flex to a right angle, an essential position for sitting. Twelve hips gained more than 90 degrees of flexion and two approached normal, flexing 35 degrees beyond a right angle. Four hips after arthroplasty failed to extend to 160 degrees; the others extended between 160 and 180 degrees. Only four hips failed to maintain at least 10 degrees of abduction after operation; the others had 10 to 40 degrees of abduction, with an average of 25 degrees. Six hips had less than 5 degrees of internal rotation; the others maintained 5 to 30 degrees, with an average of 20 degrees.

Pain: Pain is subjective and is therefore difficult to classify. Comparison of preoperative and postoperative pain symptoms is shown in Chart II. Perhaps the most outstanding gain achieved by the patients in this series is the relief of pain following arthroplasty.

Walking: The four patients unable to walk postoperatively presented particular problems. For these, the main objective of arthroplasty was to simplify nursing care and hygiene problems caused by the fixed deformities of the joints of the lower limbs. Postoperatively the patients were able to sit, whereas preoperatively they were completely bedridden. Thirty-three of the patients were able to walk prior to surgery, but their ability to walk had been diminishing progressively. Arthroplasty enabled them to maintain this ability.

COMPLICATIONS FROM SURGERY

Deaths

Two deaths were encountered in this series, making the total number of patients considered fifty instead of the forty-eight analyzed from a follow-up standpoint. One of these deaths was proved to be due to an error in laboratory cross-matching of blood for surgical transfusion.

The other death occurred in a patient who had been receiving steroid therapy.

FIG. 3-A

Appearance of the left hip before arthroplasty. The patient had flexion-adduction contracture with painful deformity and painful joint crepitus on attempted motion. Flexion was possible to 10 degrees beyond a right angle, extension to 160 degrees, internal rotation to 10 degrees, external rotation to 5 degrees, adduction to 25 degrees, and abduction to 25 degrees. All motion was painful and the patient walked with a crutch. Eleven months after surgery, breakdown of the wound occurred with persistent drainage until removal of the cup approximately three years later.

FIG. 3-B

Appearance of the hip after removal of the cup. The wound had healed and the patient had flexion of 90 degrees; extension, 155 degrees; abduction, 20 degrees; adduction, 10 degrees; external rotation, 20 degrees; and internal rotation, 10 degrees. The patient had pain when walking without either crutches or cane and with prolonged weight-bearing. He could sit in a standard chair, drive a car, and work daily. Chronic granulation tissue, sinus tract, neck absorption, and a purulent exudate, hemolytic *Staphylococcus aureus*, were encountered at the last operation. The acetabulum and the stump of the head and neck had a smooth fibrous lining.

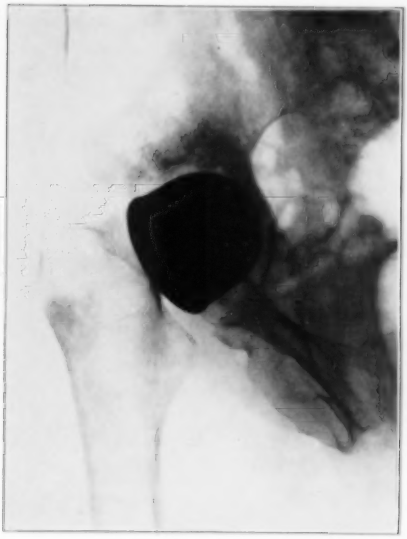

FIG. 4-A

FIG. 4-B

Fig. 4-A: Roentgenogram of the fractured neck of the femur inside the cup eight weeks after arthroplasty. Fracture occurred as patient alighted from the front seat of an automobile.

Fig. 4-B: View of the hip as it appeared four months after the trochanter was transplanted into the acetabulum using a Smith-Petersen cup twelve weeks after the first arthroplasty. The range of motion on January 20, 1959, was: flexion, 100 degrees; extension, 180 degrees; abduction, 30 degrees; adduction, 30 degrees; internal rotation, 10 degrees; and external rotation, 10 degrees. The patient was free of pain, walked with crutches, and sat in a standard chair. She did her own light housework, and put on stockings with starting aids. On examination, the hip crunched and grated but the amount of callus apparently had not resulted in arthrodesis.

Total adrenal failure and hemorrhage were noted at autopsy. For ten to twelve months prior to surgery this patient had received thirty to forty milligrams of cortisone daily. No increase in dosage was given at the time of surgery and about three hours after returning to his bed from the operating room, peripheral vascular collapse developed without evidence of hemorrhage or blood loss to explain this complication. Large doses of cortisone failed to bring him out of shock. Of course, it is now realized that in patients who are taking cortisone, the dosage must be increased preoperatively.

Postoperative Wound Infections

No immediate postoperative wound infections were encountered. However, in two hips the operative wound broke down and became secondarily infected six to eight months after surgery when the patients were well along in their rehabilitation programs.

In both instances—one in a patient with a Smith-Petersen cup and the other a Naden-Reith prosthesis—a fluctuant swelling developed in the operative scar with no local heat or evidence of cellulitis. By aspiration, fluid, resembling synovial fluid, was obtained which was sterile on culture. Spontaneous drainage ensued and both wounds became secondarily infected with hemolytic *Staphylococcus aureus*.

The Smith-Petersen cup was removed two and one-half years after arthroplasty. Twelve months later the drainage had ceased and the wound had healed. The patient was walking and had a useful range of hip motion consisting of 90 degrees of flexion, 155 degrees of extension, 20 degrees of abduction, 10 degrees of adduction, 10 degrees of internal rotation, and 20 degrees of external rotation (Figs. 3-A and 3-B).

The Naden-Reith prosthesis was removed two years after its insertion and

FIG. 5-A

Roentgenogram of the right hip before arthroplasty. The patient had fibrous ankylosis, springy motion, painful flexion-abduction deformity, and was unable to bear weight. He was confined to a wheel chair or bed.

FIG. 5-B

Eight months after cup arthroplasty, the patient sustained intertrochanteric fracture of the right hip while anaesthetized for arthroplasty on the left hip. This was treated by skeletal traction and a balanced Thomas splint for two months after which mobilization was allowed. Four years later there was extension to 175 degrees; flexion, 75 degrees toward a right angle; adduction, 30 degrees; abduction, 20 degrees; internal rotation, 30 degrees; and external rotation, 20 degrees. Since that time, the patient has had arthroplasty done on the opposite hip, walks with crutches, drives a car, and works daily. There is minimal to moderate pain with prolonged weight-bearing.

the greater trochanter placed in the acetabulum. Three months after this second procedure drainage had almost ceased and hip motion was maintained with flexion to 100 degrees and extension to 180 degrees. The patient was walking with crutches.

There were two other instances in this series where delayed breakdown occurred with spontaneous drainage which was sterile on culture. Both of these

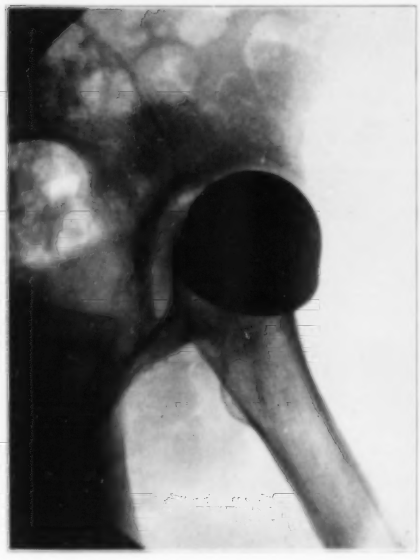

FIG. 6-A

FIG. 6-B

Roentgenograms made after arthroplasty show that external torsion of the femur, present prior to arthroplasty, was not corrected. Anterior subluxation of the cup and femoral neck was noted three months after arthroplasty, as weight-bearing was started. The hip is stable in this position. Five years after arthroplasty, motion was: extension, 180 degrees; flexion, 80 degrees; adduction, 30 degrees; abduction, 35 degrees; internal rotation, zero; and external rotation, 20 degrees. The patient was free of pain, walked with a crutch or a cane, drove a car, and worked daily as a medical laboratory technician. Before surgery, the patient had had no effective motion, other than springy fibrous ankylosis, pain, and had been unable to sit.

wounds healed spontaneously and no further drainage had occurred after eighteen and twenty months, respectively.

It is believed that drainage which occurred in these four patients was due to intolerance to the metal even though there was no evidence of erosion in the two appliances that were removed. The tissue reaction in these patients resembled that seen in the formation of traumatic bursa.

Peroneal Palsy

After operation four patients showed transient peroneal palsy due to prolonged adhesive traction. None of these cases proved to be permanent, and a spring drop-foot brace worn by the patient during the recovery period permitted rehabilitation of the hip without interference.

Cup and Prosthetic Problems

Cup: One patient, after cup arthroplasty, sustained a spontaneous fracture of the base of the femoral neck with the result that the stump of the neck displaced the Smith-Petersen cup, requiring reoperation four months after arthroplasty. In this procedure the proximal fragment of the neck was discarded and an osteotomy was performed through the base of the greater trochanter. A Smith-Petersen cup was placed on the stump of the neck and the trochanter displaced downward onto the proximal part of the femoral shaft (Figs. 4-A and 4-B). Thirty months after this second procedure this hip had full extension, flexion to 100 degrees, abduction and adduction of 30 degrees each, 10 degrees internal rotation, and 10 degrees of external rotation. Another patient had a subtrochanteric and intertrochanteric fracture of the femur below and adjacent to the Smith-Petersen cup while anaesthetized and being prepared for arthroplasty on the opposite hip (Figs. 5-A and 5-B).

FIG. 7-A

Before arthroplasty, there was painful motion and the patient walked with crutches. He had pain sitting or at rest. Motion was: extension, 170 degrees; flexion, 20 degrees beyond a right angle; internal rotation, 30 degrees; external rotation, 30 degrees; abduction, 10 degrees; and adduction, 15 degrees.

FIG. 7-B

Dislocation of the neck of the stump occurred eighteen months after arthroplasty. The patient applied a one-inch lift to his shoe fifteen months after arthroplasty to correct gluteal limp and apparent shortening. Prior to applying the lift, there was no pain; extension to 180 degrees; flexion to 20 degrees beyond a right angle; abduction to 40 degrees; adduction to 30 degrees; and internal and external rotation to 25 degrees each. After the lift was applied, pain was present when the patient was resting and during weight-bearing. Motion remained the same except for loss of abduction. The cup appeared tilted and rotated in roentgenograms made three months after he applied the lift. The patient died from ruptured peptic ulcer after taking cortisone without medical control.

This fracture was treated conservatively by skeletal traction and suspension on a Thomas splint for eight weeks. Active and passive exercises for this hip were then resumed. In spite of this complication a satisfactory range of motion was obtained four years later.

One patient, a hospital laboratory technician, has anterior subluxation but the hip is asymptomatic. He has flexion to 10 degrees beyond a right angle, 35 degrees of abduction, 30 degrees of adduction, 180 degrees of extension, and 20 degrees of external rotation. However, he has a fixed external rotation deformity of 10 degrees. It is now six years since operation and no further treatment is planned (Figs. 6-A and 6-B).

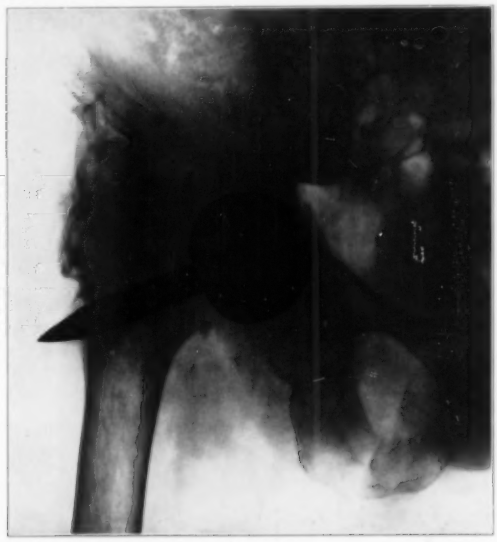

FIG. 8

Roentgenogram made four years after arthroplasty shows Naden-Reith prosthesis wandering. Wandering began fourteen months after arthroplasty and is progressing. The hip was painless on weight-bearing with crutches. The patient could sit in a standard chair and drive a car with automatic transmission. There was extension to 180 degrees; flexion to 100 degrees; adduction to 30 degrees; abduction to 10 degrees; internal rotation to 10 degrees; and external rotation to 15 degrees. The patient has moderate pain on prolonged weight-bearing without crutches but, prior to arthroplasty, had been confined to a wheel chair.

In another patient the cup, as mentioned previously, was removed because of delayed breakdown of the wound six to eight months postoperatively and secondary infection which is healing at the time of writing. This hip now has 155 degrees of extension; flexion, 90 degrees; abduction, 10 degrees; adduction, 20 degrees; and external and internal rotation of 10 degrees which has been maintained after removal of the cup. This patient walks with crutches, drives her own car, and works daily as a bookkeeper.

The stump of the neck dislocated from the cup and could be reduced only by reoperation in another patient. However, this patient, two years after arthroplasty, had taken it upon himself to apply a one and one-quarter inch lift to the sole of his shoe because of his gluteal limp which he attributed to shortening of the limb. Actually the real length of the leg on the operated side was only one-half inch less than the unoperated side. It is the author's belief that the lift threw an adduc-

tion thrust on the cup rotating it inward and allowing the femoral neck to dislocate. This is considered neither a technical error nor a fault of the procedure, yet is classified as a failure (Figs. 7-A and 7-B).

FIG. 9-A

Roentgenogram showing hips before uncomplicated arthroplasty.

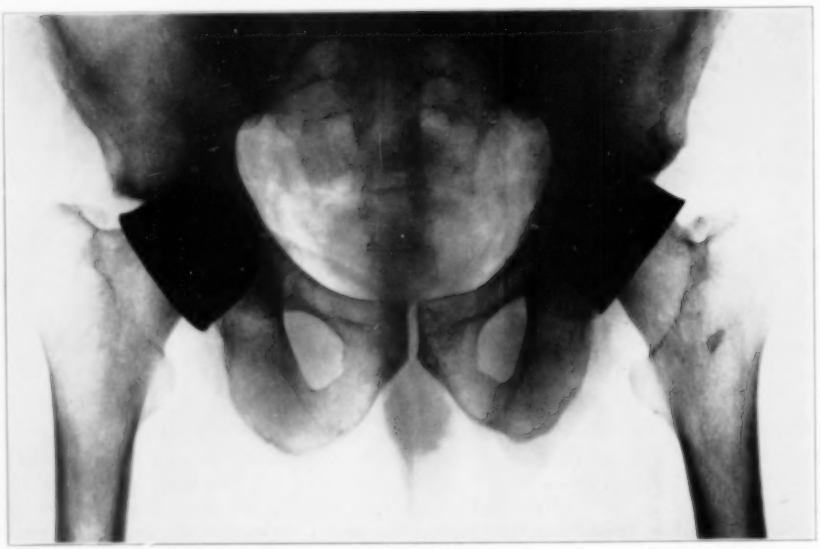

FIG. 9-B

The patient had uncomplicated, Smith-Petersen cup arthroplasty performed bilaterally. There was a four-year follow-up on the right hip, and a three-year follow-up on the left. Preoperatively, there was bilateral, disabling pain when walking with crutches. Although preoperative and postoperative motion was the same, the patient was free of pain in both hips after arthroplasty and could walk without crutches. Motion was the same in both hips: extension, 180 degrees; flexion, 20 degrees beyond a right angle; abduction, 40 degrees; adduction, 40 degrees; internal rotation, 35 degrees; and external rotation, 25 degrees. The patient could put on stockings, drive a car, and sit in a standard chair.

Naden-Reith prosthesis: Three of the fifteen prostheses loosened and two stems wandered postoperatively, five and three years, respectively. None of these prostheses have as yet required removal, but reoperation will eventually be necessary. All three patients use crutches due to the severity of arthritis in other joints.

FIG. 10-A

Roentgenogram made before surgery.

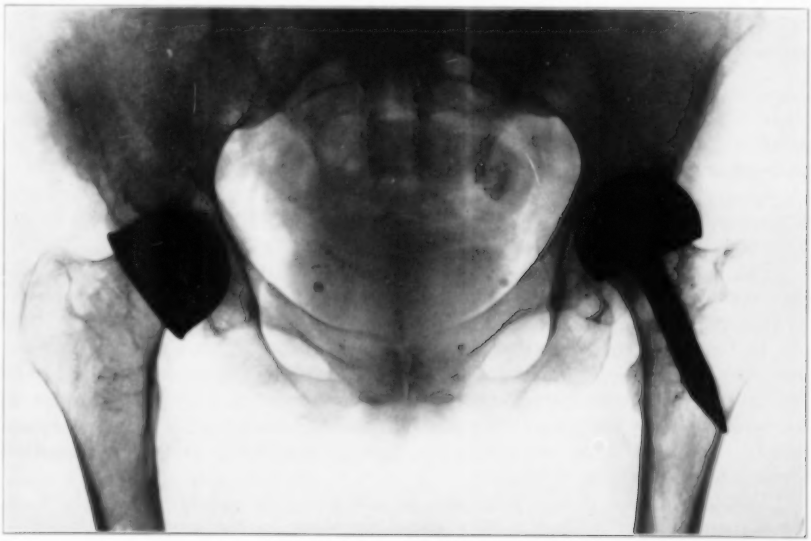

FIG. 10-B

Roentgenogram showing a Naden-Reith prosthesis in the left hip and a Smith-Petersen cup in the right hip after a six-year follow-up. Preoperatively, there was disabling pain in both hips and the patient was confined to a wheel chair. Postoperatively, the patient could walk with crutches or canes, was free of pain, and sat in a standard chair. The range of motion in both hips was: extension, 180 degrees; flexion, 20 degrees beyond a right angle; adduction, 40 degrees; abduction, 35 degrees; internal rotation, 40 degrees; and external rotation, 30 degrees. Although the hips functioned well, the patient had stiff knees and stiff ankles.

These hips have so far maintained useful motion and have been comfortable, permitting walking, driving a car, and daily work (Fig. 8).

FINAL EVALUATION

When this study was started it was elected to use the Smith-Petersen Vitallium cup where there was sufficient femoral head and neck for an adequate reconstruction of the joint and to use the stainless-steel Naden-Reith prosthesis for those patients where there was so much softening or deterioration of the head that it was considered advisable at the time of operation to remove the head. The results from these two types of reconstruction have been the same from the standpoint of the range of motion, strength, gait, and pain except in those patients where the prostheses worked loose. With increasing experience the author, because of the tendency for these prostheses to work loose, has been influenced to use the Vitallium cup, more frequently placing the cup on the neck and transplanting the greater trochanter downward when feasible (Figs. 9-A and 9-B). However, the

TABLE I

ANALYSIS OF END RESULTS OF SIXTY-EIGHT PATIENTS

Follow-up (*Years*)	Results			
	Good	Fair	Poor	Failure
1	3	2	4	0
2	6	3	3	0
3	8	2	2	1
4	6	6	2	2
5	6	1	3	0
6	1	2	1	0
7	2	1	0	0
8	0	0	1	0
9	1			
Total	32	17	16	3
Per Cent	48	25	22	5

Naden-Reith prosthesis has proved to be entirely satisfactory in those patients where it has seated well and remained stable (Figs. 10-A and 10-B). I have had no experience with the other types of prostheses for reconstruction performed for rheumatoid arthritis.

Giving due consideration to the requirements and objectives of patients with rheumatoid arthritis, I have set up the following standard for grading the results in these sixty-eight hips:

The end results are graded: *good*, *fair*, and *poor*, or *failure*, according to the general evaluation of the patient before and after surgery (Table I). The following criteria have been established:

To be considered *good*, the patient's ability to walk must be restored or improved as the result of surgery or he must maintain the ability to walk which he was losing prior to surgery. The patient must regain a fully useful range of motion in the hips with the ability to walk without assistance. Pain must be relieved to enable average use of the hip, and the mechanics of the reconstructed hip must appear to be acceptable.

To consider the results *fair*, hips in this category satisfy previously mentioned requirements but lack a fully useful range of motion for walking or sitting and in some instances the reconstructed joint is mechanically defective. The patient continues to require some help, but is no longer a total invalid.

End results were considered *poor* when the hips were unsatisfactory and definitely required subsequent reoperation. These patients had gained little toward being self-sustaining or had failed to gain more than 40 per cent of the range of motion necessary for sitting, standing, and walking.

End results were classified as *failures* when the patient's condition was worse after surgery, if he had no improvement in function, or had noted no relief from pain following operation.

Requiring custom-built aids such as shoes or chairs and using crutches or canes for walking did not alter the end-result classification.

The number of patients in each category at the time of rating the end results are shown in Table I. Six of the seven arthroplasties whose end results were classified *poor* in the one and two-year follow-up columns were done on three patients purely for purposes of simplifying nursing care; this was accomplished. The greater incidence of poor results in these two columns does not necessarily reflect errors of technique or of selection. It is my opinion that good and fair results, representing a satisfactory degree of improvement, can be anticipated in 73 per cent of the hips operated upon in selected cases of rheumatoid arthritis.

Rheumatoid Synovial Cyst of the Hip

Report of Three Cases *

BY MARK B. COVENTRY, M.D., HOWARD F. POLLEY, M.D., AND ALAN D. WEINER, M.D., ROCHESTER, MINNESOTA

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Recently we encountered three patients with advanced rheumatoid arthritis, each of whom had a synovial-lined cyst presenting anteriorly from the hip joint into the inguinal region. The diagnosis was not made preoperatively in any of these three; perhaps, on the basis of our experience, the condition may be more readily recognized in the future.

Cysts of the hip joints have not often been described in the literature but when they were they were generally attributed to traumatic, infectious, or spontaneous communication of an enlarged iliopectineal bursa with the adjacent hip joint [8,9,11,13,17]. Although an occasional instance of arthritis (presumed to be of the degenerative type [8]) or rheumatoid spondylitis [13] was recognized, the occurrence of synovial cyst of the hip in patients with rheumatoid arthritis has not been clearly described. A report of our cases follows.

Case 1. A white male laborer, fifty-six years old, was admitted to the Mayo Clinic because of rheumatoid arthritis, and a right inguinal mass which had been present for six months. The swelling was not associated with injury and was painless. The patient had a history of extensive rheumatoid arthritis of at least fifteen years' duration, but otherwise had been in good health. During the six months preceding the examination at the clinic he had reportedly received gold and ACTH, without appreciable benefit.

* Read at the Joint Meeting of the Orthopaedic Associations of the English-Speaking World, Washington, D. C., May 16, 1958.

† The Mayo Foundation, Rochester, Minnesota, is a part of the Graduate School of the University of Minnesota.

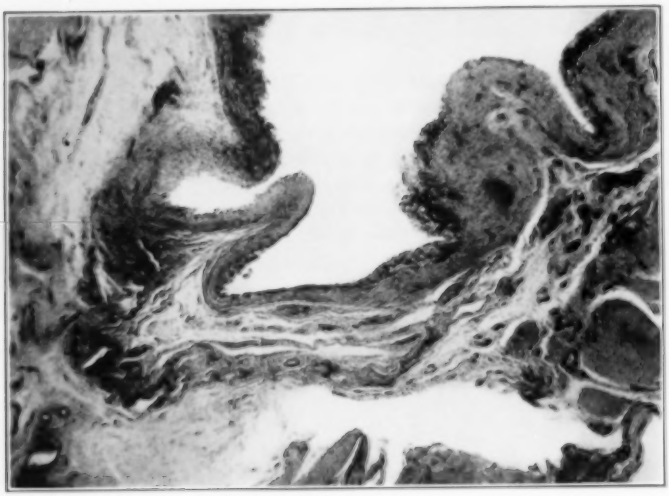

FIG. 1-A

Case 2. Section of synovial lining of the cyst on the right hip (hematoxylin and eosin, × 19). Thickening of the synovial lining and villous formation are seen in this view through the low-power objective.

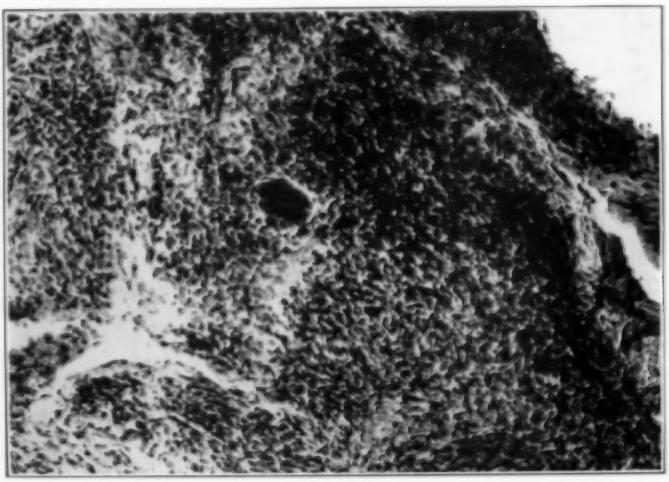

FIG. 1-B

Same view, with the high-power objective. Note the perivascular collections of lymphocytes and plasma cells, a giant-cell formation beneath the thickened lining layer of the cyst, and a few osteochondromatous foci (hematoxylin and eosin, × 187).

Examination revealed multiple deformities of joints, limitation of motion, residual synovial thickening, and muscular atrophy of fingers, wrists, elbows, shoulders, feet, ankles, and knees. Bilateral popliteal cysts were present and there was an apparent extension of the synovitis of the wrists distally along the extensor surfaces of both hands. Multiple subcutaneous rheumatoid nodules were present in both hands and the left forearm. The left hip was limited in motion, but the range of motion of the right hip was normal. An irregular cystic mass, approximately three by four by four inches, was seen and felt in the right groin. It did not pulsate, was not tender, and there was no bruit.

The erythrocyte sedimentation rate was 78 millimeters in one hour (Westergren), and albuminuria was graded ++ (on the basis of 0 to ++++), but results of blood counts and of urinalysis in other respects were normal.

Roentgenograms disclosed destructive changes in the sacro-iliac joints and the left hip. The right hip appeared to be normal.

After sterile preparation, and with the patient under the influence of local anaesthesia, the mass in the right groin was punctured with a needle. A thick, purulent-appearing fluid was aspirated from what appeared to be a cold abscess. A culture was made from a specimen of this fluid but bacterial growth, including acid-fast bacilli and Brucella organisms, was not produced, nor were fungi. Inoculation of guinea pigs with some of the material produced no evidence of tuberculosis.

It was concluded that the cyst probably was connected with the hip joint, that it was the result of changes due to rheumatoid arthritis, and that the material which had been aspirated was sterile synovial fluid containing necrotic debris and fibrin. Six years later the patient reported that the mass in his right groin had completely disappeared, but a smaller and similar one had shown up in his left groin.

Case 2. A white housewife, sixty-three years old, consulted the Mayo Clinic because of swelling in the right groin of two years' duration. Eighteen months after the onset of this swelling she had consulted her local physician because of diffuse swelling in her right leg. He incised and obtained fluid from the mass in the right groin. The wound subsequently healed and the swelling of the right leg decreased considerably. However, after the mass in the groin had temporarily decreased, it gradually increased.

This patient had had rheumatoid arthritis for thirty years; otherwise her health had been good. She had begun to use crutches twelve years after the onset of symptoms of arthritis. Examination disclosed rheumatoid deformities and marked limitation of motion of the hands, wrists, elbows, left shoulder, ankles, and feet. Flexion contracture and apparent fibrous ankylosis of the right knee joint also were found. Peripheral oedema of the right lower extremity was graded ++ (on the basis of 0 to ++++). In the right inguinal region was a small, one by one by one inch, mass with a thickened, indurated scar at the site of the previous incision.

The erythrocyte sedimentation rate was 55 millimeters in one hour (Westergren). Results of other laboratory tests, including blood counts and urinalysis, were within normal limits. Roentgenographic examination of the pelvis and hips showed a small osteoporotic or destructive area in the upper outer aspect of the right femoral head. The joint of the right hip was moderately narrowed.

The right inguinal mass was explored and found to be heavily scarred to the surrounding soft tissues. It contained synovial fluid and was continuous with the right hip joint through a communication large enough to admit the index finger. The sac was removed, and the anterior portion of the hip joint inspected. The cartilage of the femoral head was yellowish brown, but intact. The synovial membrane of the hip was reddened, thickened, and villous. The capsule of the hip joint was sutured and the wound was closed.

Pathological examination showed the collapsed synovial sac to be approximately seven centimeters in diameter. The synovial membrane lining the walls of the sac showed perivascular collections of lymphocytes and plasma cells, such as are seen in the presence of rheumatoid synovitis. There also were a few foci of osteochondromatous changes in the synovial sac (Figs. 1-A and 1-B).

The patient's convalescence was complicated by the development of thrombophlebitis in the right lower extremity, but this subsided satisfactorily under treatment and the wound healed by first intention.

Five years later she was confined to bed as an invalid. The right lower extremity remained swollen, and there was pain in the right hip region with limited motion. No mass was present in the right inguinal region.

Case 3. A white director of a girls' camp, sixty-one years old, consulted the Mayo Clinic because of marked swelling of the left lower extremity which had been present for about eight months. The onset was gradual, without pain or injury.

He had had symptoms of rheumatoid arthritis for fifteen years with involvement of multiple joints, but had continued his work while taking cortisone orally in doses of seventy-five to 150 milligrams daily for the preceding four years. During this time marked hypercortisonism had developed [16]. Furthermore, for about four years he had had a chronically infected, draining ingrowing toenail on the left great toe. He also gave a history of symptoms referable to the genitourinary tract. Micturition was necessary three to four times during the usual resting hours; there was intermittently increased daytime frequency of urination, sometimes occurring as often as every twenty to thirty minutes; and during the previous three years, a weakness and slowing of the urinary stream.

Examination showed characteristic and extensive involvement by rheumatoid arthritis. The elbows were flexed, wrists were limited in motion, the proximal interphalangeal joints

of the fingers were subluxated, the left knee was slightly flexed, and both knees were markedly swollen. There was residual boggy synovial thickening in the ankles and feet, as well as in the other affected joints mentioned previously. Abduction and rotation in the right shoulder were markedly limited. Movement of both hips was limited to grade +++

FIG. 2-A

Case 3. Anteroposterior roentgenogram of the pelvis showing marked destructive changes in the left hip and loss of joint space, with some marginal sclerosis in the right hip.

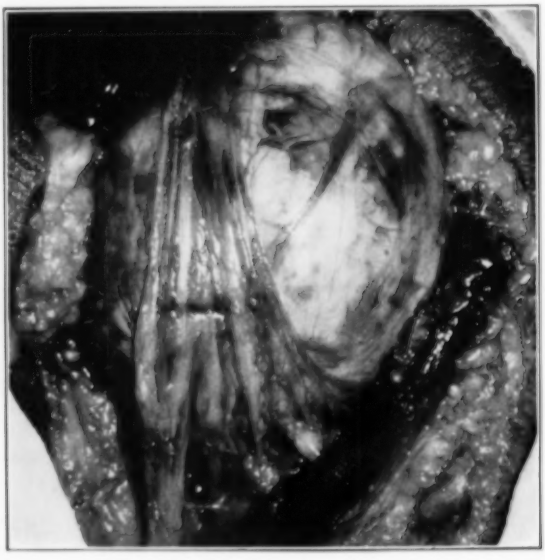

FIG. 2-B

Appearance of the cyst after it had been dissected free from the overlying skin. Note the bulging of the cyst of the left hip and the femoral nerve and femoral vessels stretched over it.

FIG. 2-C

The cyst of the left hip was removed and upon opening it hypertrophic and villous proliferation of the lining membrane was disclosed.

FIG. 2-D

Section of the rheumatoid synovial cyst of the left hip removed from the inguinal region. There is a fibrinous exudate overlying the lining membrane. Beneath the lining membrane is marked infiltration of inflammatory cells (hematoxylin and eosin, × 31.5).

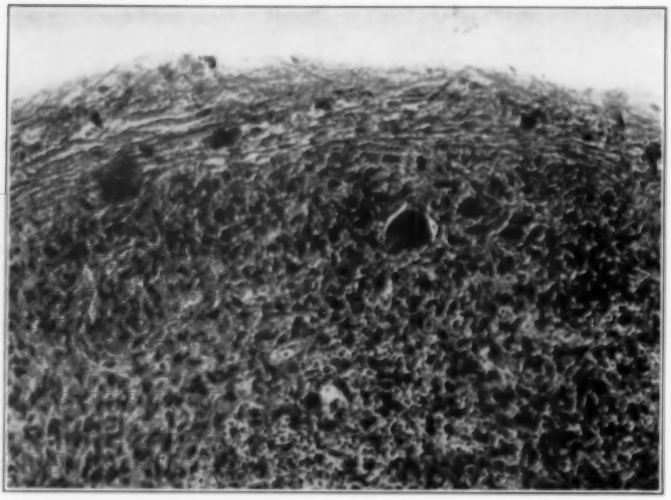

FIG. 2-E

Fig. 2-E: High-power magnification of same specimen, showing cellular infiltration with some giant cells in the tissues beneath the synovial lining and the overlying fibrinous exudate. In other areas small focal calcific deposits and slight perivascular infiltration of small round cells were also seen (hematoxylin and eosin, × 217).

(on the basis of 0 to ++++) in all directions. Pitting oedema of the entire left lower extremity was graded +++ (on the basis of 0 to ++++). A globular mass, three inches in diameter, was visible in the left groin below the inguinal ligament at the base of the femoral triangle. It was firm, fixed, and somewhat cystic on palpation. It was not tender, did not pulsate, and no bruit could be heard. The prostate gland was moderately enlarged, stony hard, and in the opinion of the consulting urologist, had the consistency characteristic of prostatic carcinoma; this was treated with stilbestrol.

There was marked evidence of chronic hypercortisonism, including facial rounding, increased deposits of fat in the supraclavicular and retrocervical regions, ecchymosis, gain in weight, gynecomastia, and elevated blood pressure. The patient had periods of mental stimulation with cyclic swings of mood, increased fatigability, and generalized aching simulating a flare of active rheumatoid arthritis. These symptoms were noted especially while he was taking doses of cortisone irregularly or when he was attempting too large a reduction of the dose from time to time[15].

The left great toenail was embedded medially in a mass of granulation tissue, and seropurulent drainage was present with a small area of surrounding cellulitis.

The erythrocyte sedimentation rate was 46 millimeters in one hour (Westergren); the value for acid phosphatase was 6.1 King-Armstrong units per 100 cubic centimeters of serum; leukocytes numbered 3,000 per cubic millimeter, with a differential, in percentage, of 31 for lymphocytes, 1 for monocytes, and 68 for neutrophils; the value for hemoglobin ranged between 11.7 and 9 grams per 100 cubic centimeters of blood; the value for urea was 42 milligrams per 100 cubic centimeters of blood, and the results of urinalysis were within normal limits.

Roentgenograms disclosed destructive changes in the left hip and some marginal sclerosis in the right hip (Fig. 2-A).

The mass in the left groin obviously was obstructing the lymphatic return from the left lower extremity, but the relationship of the mass to the long-standing infection in the left great toe or to the rheumatoid arthritis or hypercortisonism, was not clearly defined preoperatively. The appearance and location of the mass did not indicate the likelihood of any relationship between it and the carcinoma of the prostate gland.

Surgical exploration after preoperative preparation with cortisone[16,18] was done through a longitudinal incision extending from three inches proximal to the inguinal ligament downward, over the mass, to the apex of the femoral triangle. The subcutaneous fat and fascia had been stretched thin. They were incised, and a large, bulbous mass, round and regular, presented itself. The femoral nerve was stretched tautly across the mass (Fig. 2-B). The nerve was dissected free and retracted laterally. The femoral vein and artery were identified and retracted medially with a soft rubber drain. The confines of the mass were care-

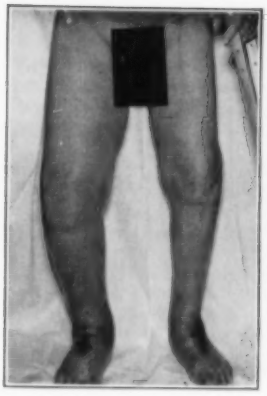

FIG. 2-F

FIG. 2-G

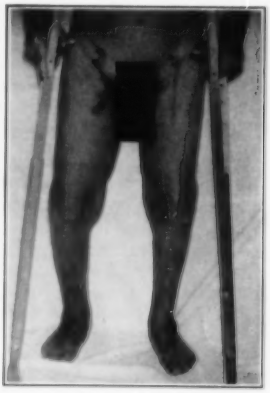

FIG. 2-H

Fig. 2-F: Patient twenty-two months later, after excision of synovial cyst of the left hip. Marked swelling of the right lower extremity caused by a synovial cyst of the right hip in the inguinal region is present. Similar swelling of the left lower extremity had been present prior to excision of the synovial cyst from the left side.

Fig. 2-G: Appearance of the synovial cyst after surgical exposure.

Fig. 2-H: The same patient nine days after excision, from the right inguinal region, of the synovial cyst of the hip. The oedema of the right lower extremity has disappeared.

fully delineated by sharp and blunt dissection, which disclosed a pedicle of the mass extending into the hip joint anteriorly. The mass was opened and found to be filled with a milky, fibrinous fluid. This was evacuated and a communication large enough to admit two fingers was found between the sac and the hip joint. The sac was then removed. The opening into the hip joint was enlarged, an action which showed that the articular cartilage was almost completely destroyed. The synovial membrane of the hip appeared to be similar to that of the sac; it was hypertrophied, villous, covered with necrotic debris, and was pale gray. Débridement of all visible synovial lining was then done in an effort to remove the accessible membrane obviously affected by the rheumatoid arthritis. A superficial inguinal lymph node was dissected out for pathological examination and the wound was closed. The left great toenail was then removed and the adjacent infected granulation tissue excised.

Pathological examination of the tissue removed from the left inguinal region revealed a collapsed synovial sac ten centimeters in diameter lined by subacutely inflamed synovial membrane (Fig. 2-C). There were hemosiderin pigmentation, scattered giant-cell formation, and a few areas of ossification (Figs. 2-D and 2-E), but proliferation of synovial cells was not seen.

Culture of specimens of the fluid and tissue for tuberculosis, Brucella organisms, fungi, and the usual pathogens gave negative results.

Within a day after operation there was a distinctive decrease in the lymphoedema of the left lower extremity, and within three days it had entirely disappeared. When the wound had healed, the patient was allowed to walk, wearing an elastic stocking. No recurrence of the oedema was evident after activity within the limits of that which could be anticipated in view of the articular damage arising from the rheumatoid arthritis.

The patient returned ten months later. He said that a week prior to this second admittance to the hospital he had noticed diffuse swelling of the right lower extremity and, a few days later, slight swelling in the right groin. Examination disclosed a diffuse, cystic enlargement in the right groin similar in location, appearance, and palpation to the cyst of the left hip, but only about a quarter of the size. The oedema promptly subsided after rest and elevation. Aspiration of the contents of the cyst was carried out and after two fluid ounces of cloudy yellowish fluid had been removed, 62.5 milligrams of hydrocortisone acetate was injected. There was no visible or palpable change in the size of the cyst on subsequent days. Surgical removal of the lesion was advised, but declined by the patient.

The patient was re-examined a year later. He reported that swelling of the right leg had continued in variable degree during this interval, but had become worse two to three months prior to this visit. Because of the increased swelling, eighty cubic centimeters of fluid had been aspirated. Hydrocortisone acetate had been injected ten weeks prior to his re-examination; only temporary relief was obtained. Another 100 cubic centimeters of fluid was aspirated and additional hydrocortisone acetate was injected just nine days prior to the patient's return to the clinic; these measures did not bring about any recognizable relief.

An ill-defined mass was noted in the right inguinal region; this mass felt dumbbell

shaped, firm, and cystic. Moderate oedema of the lower extremity was seen distal to the inguinal ligament (Fig. 2-F). Excision of this cyst was advised.

After preoperative preparation of the patient with cortisone, the synovial cyst was excised (Fig. 2-G). It was found to be divided roughly into two portions by the inguinal ligament. It passed cephalad along the psoas tendon and distally below the ligament approximately three inches, stretching the sartorius muscle over it and displacing the femoral artery, vein, and nerve laterally. An opening one and one-half inches in diameter was present between the cyst and the hip joint.

The synovial membrane of the hip joint and the cyst was villous and somewhat brownish. The cyst was excised, together with the synovial membrane from the front of the hip joint without dislocation of the hip, and the wound was closed. On microscopic examination the wall of the cyst was seen to be lined by necrotic fibrin, which in some areas exhibited deposits of calcium. The inflammatory reaction seen histologically in both the wall of the cyst and the synovial lining of the hip joint had the typical characteristics of rheumatoid arthritis.

The oedema in the right lower extremity disappeared within forty-eight hours and healing of the wound took place without incident (Fig. 2-H). One year later the patient reported that there had been no evidence of recurrence of swelling in either the inguinal regions or the legs. Two years after dismissal from the clinic he died of pericarditis. There had been no recurrence of either cyst.

COMMENT

Whether all synovial cysts of the hip are the results of a communication between the hip joint and an adjacent enlarged iliopectineal bursa remains to be clarified. However, in all three of the patients reported upon here a similar course of events had taken place: the patients were more than fifty-five years old, their rheumatoid arthritis was extensive, chronic, and of long duration (fifteen or more years), and in each there was a gradual and more recent appearance of a painless mass in the groin. In two patients there was associated lymphoedema of the extremity below the mass.

Cause of Rheumatoid Synovial Cysts

At least three theories which might be applicable to the occurrence of synovial cysts of the hip in patients with rheumatoid arthritis can be postulated to explain the pathogenesis of these cysts.

First, the overproduction of synovial fluid in a rheumatoid joint might increase the intra-articular pressure and distend the capsule of the joint. Anteromedial to the iliofemoral ligament [10] the capsule normally is thin or sometimes has an aperture which allows direct communication with the overlying iliopectineal bursa. The capsule of the joint may be weakened further by degenerative changes secondary to the rheumatoid arthritis. The herniated sac or cyst thus may be simply an extension or protrusion of the synovial membrane of the hip similar to that which can occur in other joints, such as the knee [2].

A second theory is quite different, but it also may be applicable to the cases herein described. According to this theory, the iliopectineal bursa, which sometimes communicates anteromedially with the hip joint [4,10,12], may become involved in the rheumatoid process with formation of excessive quantities of fluid, enlargement of the bursa, and hypertrophic and villous proliferation of the bursal lining. If direct communication between this bursa and the hip joint is not present, necrosis from degenerative and rheumatoid changes and pressure from within the engorged bursa might produce a communicating channel to the hip joint. Thus, rheumatoid involvement of the iliopectineal bursa might be the original basis for the appearance of a rheumatoid synovial cyst of the hip.

A third theory seems to be a less likely explanation for the conditions in our cases. Necrosis of a subcutaneous periarticular rheumatoid nodule, as described by Bennett, Zeller, and Bauer, possibly could result in the formation of a juxta-articular cyst simulating the appearance of a synovial cyst. However, a synovial or bursal lining such as was found in our patients would not be present in such an instance.

Differential Diagnosis

In our experience, the differential diagnosis of a mass in the inguinal region would include a number of varied and unrelated conditions. In addition to the uncommon occurrence of a (1) rheumatoid synovial cyst as reported herein, enlargement may be the result of (2) inguinal adenopathy secondary to chronic infection or neoplasm, (3) herniation of abdominal contents, (4) aneurysm of the femoral artery or vein, (5) psoas abscess, and (6) primary tumors, especially lipomata [7] or rarely, synovioma [6].

Other conditions which have been described in the literature include ganglion cyst [5], pigmented villonodular synovitis [3], other disease of the hip joint, and iliopectineal bursitis [8,13]. Descriptions of the latter suggest that iliopectineal bursitis may be identical to synovial cyst of the hip.

Treatment

Because of varied diagnostic possibilities, surgical exploration is advisable if a diagnosis cannot be established otherwise. Removal of a synovial cyst from the inguinal region is indicated to relieve lymphatic obstruction and the oedema of the extremity resulting therefrom. Removal of such a synovial cyst also would be indicated before the development of oedema, if the opportunity for removal presents itself. Débridement and removal of as much of the diseased synovial membrane as can be accomplished without dislocating the hip joint may lessen the chance for re-formation of the cyst.

Although operation is the treatment of choice in a rheumatoid patient with a synovial cyst of the hip, other indicated treatment may include adequate rest and restriction of use of the affected rheumatoid joint, the use of salicylates, and appropriate physical treatment. The systemic use of adrenocortical steroids would depend upon the indications for these agents in the presence of the rheumatoid arthritis [15,18], rather than upon the presence of the cyst. Injection of hydrocortisone acetate into the cyst of the hip might be helpful in some instances. However, repeated aspiration of the contents of the synovial cyst in addition to injection of hydrocortisone acetate was not effective treatment in one of our patients (Case 3) and has not, in our experience, proved of sustained benefit in the treatment of other rheumatoid juxta-articular synovial cysts in the region of the knee.

SUMMARY

Rheumatoid synovial cyst of the hip apparently is a rare development in the course of a relatively common disease. The occurrence of rheumatoid synovial cysts of the hips in three patients with extensive chronic rheumatoid arthritis of fifteen or more years' duration is described. Theories as to pathogenesis of this condition, the differential diagnosis of inguinal masses, and the treatment of rheumatoid synovial cysts in the inguinal region are discussed.

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DISCUSSION

Mr. W. D. Coltart, London, England: Rheumatoid synovial cyst of the hip is apparently a rare condition but potentially significant. I think we should underline two points. First, that this is another swelling of the groin which we must teach our students to recognize. We must remember it ourselves and it will be, of course, reassuring to our patients to be told that this small mass which is increasing in size is not a cancer. Second, in two of the three patients, the swelling was associated with oedema of the leg which, as far as I can gather, was relieved by removal of the cyst. It may be that we have associated and accepted an oedematous leg with a rheumatic patient and perhaps if we looked further we might discover more of these cysts than the two that have been reported. It may be an important cause of the oedema of the leg in a patient with rheumatoid arthritis and we may be able to relieve at least one of the multiple disabilities by exploring and removing these cysts.

I think that Dr. Coventry suggested that patients with these cysts should always be treated by operation. I don't think he really would emphasize that. Surely in some patients there is just a symptomless synovial cyst associated with rheumatoid arthritis. In that case, of course, operation is not required.

It should be possible to make a diagnosis in many cases without necessarily resorting to biopsy. For example, an arthrogram might easily show the communication between the cyst and joint and point out the diagnosis in that way.

Dr. Philip D. Wilson, New York, N. Y.: I regret that at the outset I must state that I am not qualified to discuss synovial cysts of the hip because I have never seen one. This fact at least entitles me to say that the condition is rare. For the last twenty-five years I have worked in a hospital which has a large and active arthritis service and if any cases had been encountered in that time, I am fairly sure that I would have seen them.

The further fact that Dr. Coventry and his associates have found only three patients with these cysts in their large arthritis clinic is additional proof of this point.

I assume that it is this very rarity which stirred the authors to bring their cases to our attention. They state that the cysts presented some diagnostic difficulties because of the necessity of differentiation from hernia, aneurysm, abscess, or tumor. I would not assume that this difficulty would be too great in view of the known history and the physical findings of rheumatoid arthritis, the cystic nature of the swelling, and the ready possibility of determining its nature by aspiration and study of the withdrawn fluid, and by injection of radiopaque fluid which on roentgenographic examination would reveal the anatomy of the cyst.

The authors speculate as to the cause of these cysts and suggest four possibilities.

I would suggest that there is another possible explanation, namely, synovial cysts of joints, particularly the large ones, which may be the result of too much cortisone therapy. I base this not only on the fact that in the abstract of all the cases of the authors, there is mention of cortisone or ACTH, but also on experience at my own hospital, where, in the arthritis clinic, in the period of two years, four patients with extensive synovial cysts of the knee were found who had history of similar treatment.

All of these patients had suffered from rheumatoid arthritis for periods of from one to twenty years. The cysts were large swellings of the popliteal space and extending down the calf to the ankle. In one patient the condition was bilateral; in each instance the swellings were associated with large effusions of the knee joint.

The extent of the cyst and its communication with the knee joint was visualized in every patient by aspiration of fluid, followed by injection of radiopaque fluid and roentgenographic examination. Two of these patients were treated by surgical removal of the cysts. In both instances the anatomy of the cyst wall and the popliteal space corresponded with that of the semimembranosus bursae as described by Eyre-Brook, Thompson, and myself in the Journal of Bone and Joint Surgery, nearly twenty years ago. There was likewise communication with the knee joint through a hole in the posterior capsular ligament. The cyst extended

(Continued on page 780)

The Measurement of Hip Motion in the Sagittal and Coronal Planes

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From the Hospital for Joint Diseases, New York

Accurate measurement of the range of motion at the hip joint is important not only in evaluating disability resulting from impairment of motion but also in determining the amount of correction to be made by subtrochanteric osteotomy. However, there is no entirely satisfactory or dependable method for measuring hip motion.

In the past, the amount of flexion deformity at the hip was determined by the flexion deformity test used by Thomas as early as 1865. He described this test as follows: "Having undressed the patient and laid him on his back upon a table or other hard plane surface, the surgeon takes the sound limb and flexes it, so that the knee joint is in contact with the chest. Thus he makes certain that the spine and back of the pelvis are lying flat on the table; an assistant maintains the sound limb in this flexed position; the patient is then urged to extend, as far as he is able, the diseased limb, and this he will be able to do in a degree varying with the previous duration of the affection" (Fig. 1).

FIG. 1

The flexion deformity test. The patient is supine, the sound thigh is flexed until it is in contact with the chest thus obliterating the lumbar lordosis. The angle which the opposite thigh makes with the table is read as the angle of flexion of the thigh. There is slight flexion of the opposite thigh with respect to the table. This is normal and represents residual flexion of the thigh which persists after the development of the normal lumbar lordosis. (Reproduction of Plate 3 from *Diseases of the Hip, Knee, and Ankle Joints with Their Deformities, Treated by a New and Efficient Method* by H. O. Thomas. Liverpool, T. Dobb and Co., 1876).

From this description, it appears that this test can be applied only to those patients who have mobility of the spine and the opposite hip. This test is not applicable to patients with cases of bilateral hip arthritis or Marie-Strümpell disease where both the hip and spine may be involved, yet these are the cases in which accurate measurement of flexion deformity is a prerequisite to adequate surgical therapy. In these cases, except for the gross clinical demonstration of flexion de-

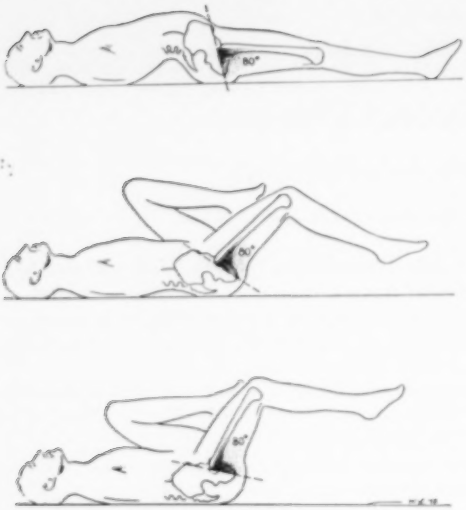

FIG. 2

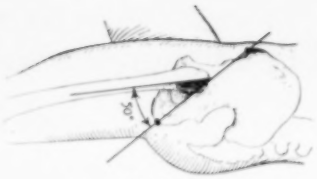

FIG. 3-A

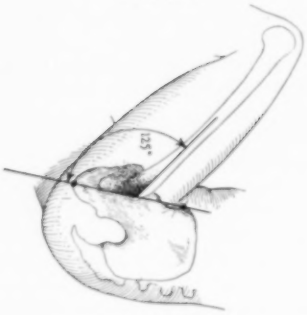

FIG. 3-B

Fig. 2: Hip-flexion deformity is shown by increased lumbar lordosis in the top illustration. The relationship of the axis of the femur to Nélaton's line is indicated by the pelvifemoral angle (80 degrees). In the middle illustration, the Thomas deformity test is being made. The relation of the femoral axis to Nélaton's line is unchanged (80 degrees), although the angle which the involved limb forms with the examining table is now approximately 45 degrees. In the bottom illustration, the relationship between the axis of the femur and Nélaton's line is still unchanged; but, by flexing the sound thigh further, the angle between the table and the involved limb has now increased to 65 degrees.

Fig. 3-A: The normal pelvifemoral angle of extension measured between Nélaton's line and the axis of the extended thigh is 50 degrees.

Fig. 3-B: The pelvifemoral angle of flexion, measured between the axis of the flexed thigh and Nélaton's line, is 125 degrees.

formity, Thomas' test will be found useless. Indeed, for the accurate measurement of flexion deformity, this test will sometimes be misleading. For example, in the examination of a patient with flexion deformity of the hip due to tuberculosis, the estimates of the deformity by ten competent orthopaedists differed by as much as 50 degrees. Similarly, one finds wide variations in the case records of patients in whom particular attention is directed toward measurement of the range of motion at the hip. Such variations are explicable only on the basis of inaccuracy. This inaccuracy occurs largely because there is no definite end point in the performance of the test. Although Thomas described flexion of the opposite hip until the knee joint touches the chest, some examiners customarily flex the opposite hip only until the lumbar lordosis is obliterated; others continue flexion until the pelvis is rolled upward off the examining table. Under such circumstances, the apparent flexion of the thigh with respect to the table is increased but without any corresponding change in the relationship of the thigh to the pelvis (Fig. 2).

On the basis of measurements made by the Thomas method, a recent description of flexion and extension at the hip indicated that forward flexion ranges from neutral position (0 degrees) to 100 degrees and backward extension from the neutral position (0 degrees) to 30 degrees [1]. These numerical values of the limits of motion represent the summation of motion at both the hip and lumbar spine. In fact, there is no backward extension of the thigh. As is well known, the embryo develops in the attitude of universal flexion. As soon after birth as the infant sits up with the thighs flexed, there is still no lumbar lordosis. Lumbar lordosis does not develop until after the infant attempts to stand. At first, this is impossible and the infant stands awkwardly with the thighs semiflexed and the spine straight or

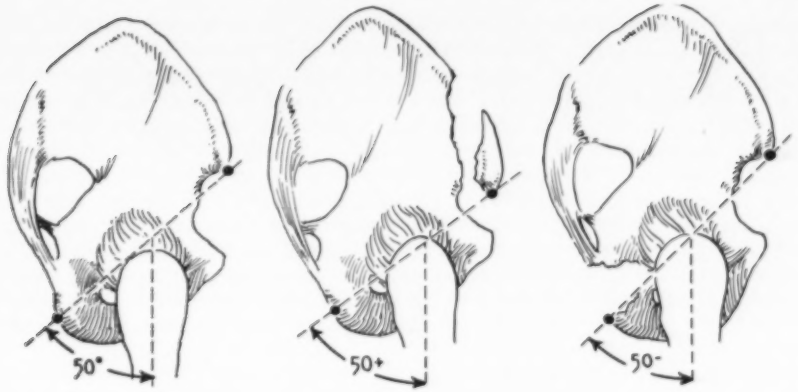

FIG. 4

The position of the points which determine Nélaton's line must be constant. Abnormal downward displacement of the anterior superior iliac spine will lead to a decrease in the obliquity of Nélaton's line and an increase in the pelvifemoral angle of extension. Downward displacement of the ischial tuberosity will lead to an increase in the obliquity of Nélaton's line and a decrease in the pelvifemoral angle of extension. In both instances the trochanter will be above Nélaton's line.

in mild kyphosis. As the child develops and extension of the thighs progresses, a point is reached at which there is maximum tension on the iliofemoral ligament; beyond this, extension of the thighs is possible only by downward tilting of the pelvis with concomitant appearance of lumbar lordosis. That complete extension of the thigh or development of normal lumbar lordosis does not occur until sometime during the second year is indicated by the fact that fractures of the femoral shaft in infants under the age of two are best aligned in the position of flexion as advocated by Bryant. It is evident that backward extension of the thigh beyond the neutral position can only mean increased lumbar lordosis with increased tilting of the pelvis. Except in cases where there is relaxation of the iliofemoral ligament and psoas tendon, it is meaningless to speak of backward extension of the thigh. What has really taken place in this position is an increased forward tilting of the pelvis.

Determination of the angles formed at a joint is possible only by measuring the angular relationship between the axis of one of the elements and the axis of the other. The pelvifemoral angle between Nélaton's line and the axis of the shaft of the femur was described in 1942 [3] and conformed with this concept. Although this term was originally used to designate the angle of greatest extension of the thigh in the sagittal plane, it is similarly applicable to the description of the greatest flexion in the sagittal plane. These two angles have been designated as the pelvifemoral angle of extension and the pelvifemoral angle of flexion, respectively. Repeated observations, confirmed by Salmore, have established the normal value for the pelvifemoral angle of extension as 50 degrees (Fig. 3-A) because tension on the iliofemoral ligament at this point prevents further change in the relationship of the thigh to the pelvis. Extension beyond this point is made possible only by downward tilting of the pelvis and an increase in lumbar lordosis.

From these considerations it is evident that flexion deformity of the hip, whether due to contracture of the capsule, of the surrounding muscle, or to intra-articular or bone hindrance, can be described as a limitation of extension. The degree of flexion deformity can be measured by the amount the pelvifemoral angle of extension exceeds the normal value of 50 degrees. Thus, a pelvifemoral angle of extension of 80 degrees represents a flexion deformity of 30 degrees (eighty minus fifty).

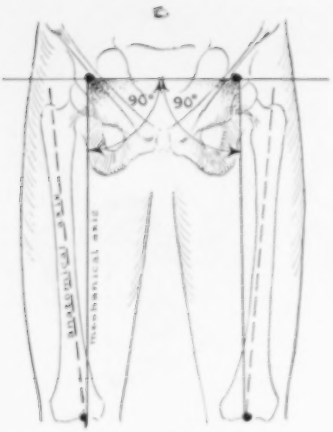

FIG. 5

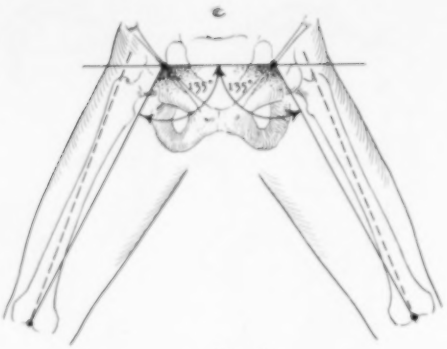

FIG. 6

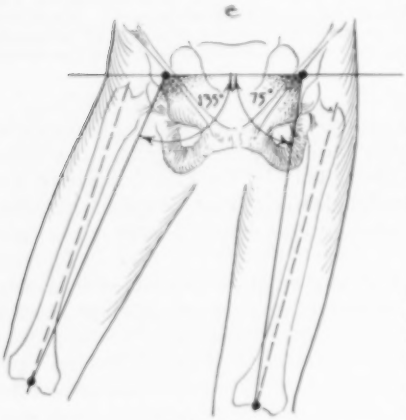

FIG. 7

Fig. 5: In a normal standing position, the mechanical axis of the femur makes an angle of 90 degrees with the interfemoral line while the anatomical axis makes an angle of 83 degrees.

Fig. 6: The co-pelvifemoral angle of abduction is determined between the mechanical axis of the femur and the interfemoral line. Normally it is approximately 135 degrees.

Fig. 7: The co-pelvifemoral angle of adduction is measured by the angle formed by the mechanical axis and the interfemoral line. With one limb in maximum abduction, adduction of the opposite limb is normally possible to an angle of approximately 75 degrees.

Since the constancy of the angle of pelvifemoral extension is determined by the restraining action of the anterior capsule and the iliofemoral ligament of Bigelow, it seems natural to inquire whether the limit of flexion of the femur with respect to Nélaton's line might not be similarly determined by the restraint imposed by the posterior fibers of the capsule. It was found that the limit of flexion of the thigh with respect to Nélaton's line was 125 degrees (Fig. 3-B). This was designated as the pelvifemoral angle of flexion. Beyond this point, there was no change in the angular relationship of the thigh to Nélaton's line, even on continued flexion of the thigh. Although the range of motion of the thigh with respect to the table may be as much as 130 degrees, the range of motion of the axis of the thigh with respect to the fixed line on the pelvis, Nélaton's line, is only 75 degrees.

Measurement of the pelvifemoral angle is made with the patient lying on one side and flexing that thigh to a right angle. The hip to be examined is uppermost. The thigh is gently extended backward. At its point of maximum extension, the anterior superior iliac spine can be felt to move downward. At this point, while maintaining the position of the thigh, the anterior superior iliac spine, the tip of the trochanter, and the ischial tuberosity are marked on the skin. The line connecting the anterior superior iliac spine with the ischial tuberosity represents Nélaton's line and will normally pass through the region of the trochanteric tip. From the tip of the trochanter, a line is drawn downward along the axis of the femur. The angle, opening downward and backward, which this line makes with Nélaton's line is the pelvifemoral angle of extension.

The thigh is now gently flexed until the anterior superior iliac spine is felt to move upward. Through the three points previously noted, the axis of the femur

and Nélaton's line are newly marked on the skin and the pelvifemoral angle of flexion is noted. The method of measuring flexion and extension at the hip by pelvifemoral angles will be found invariable and accurate to within 5 degrees, provided the position of Nélaton's line has been accurately determined before undertaking the test. It is quite evident that a change in the location of either the anterior superior iliac spine or the ischial tuberosity will alter the position and direction of Nélaton's line. Thus, downward displacement of the anterior superior iliac spine will result in a decreased obliquity of the line and an apparent increase in the pelvifemoral angle of extension. Downward displacement of the ischial tuberosity will result in an increased obliquity of the line and an apparent decrease in the pelvifemoral angle of extension. In both instances, the tip of the trochanter will be above Nélaton's line but without any diagnostic significance regarding the femoral head or neck (Fig. 4).

Although it is not absolutely positive, the relative normalcy of Nélaton's line can be determined by measuring the distance from the anterior superior iliac spine and the ischial tuberosity to the tip of the medial malleolus at the ankle. Usually these distances will be equal on both sides and any variation will indicate the need for more detailed study [2]. Except in instances of excessive obesity, the anterior superior iliac spine and the ischial tuberosity in the gluteal fold can readily be located.

To differentiate the pelvifemoral relationship in the sagittal plane from that in the coronal plane, the former has been designated as the pelvifemoral angle while the latter has been designated as the co-pelvifemoral angle.

In the past, the degree of abduction or adduction was measured by the angle made by the anatomical axis of the femur and a line drawn through both anterior superior iliac spines. This method is sufficiently accurate for clinical determinations, provided it is recalled that the anatomical axis of the femur in the symmetrical standing position makes an angle of about 83 degrees with this line. However, since subtrochanteric osteotomy is performed with the object of shifting the mechanical axis, it is suggested that this line be used as the standard of reference in making determinations of abduction or adduction or both. In order to utilize the mechanical axis most effectively, it is suggested that the interfemoral line, that is, the line joining the centers of the femoral heads, be used instead of the interspinous line.

The femoral heads are normally located slightly below the mid-point of the line which joins the anterior superior iliac spines and the pubic spines on each side. In erect symmetrical stance, the mechanical axes of the femora form right angles with the interfemoral line on each side (Fig. 5). Any increase in the angle between the mechanical axis and the interfemoral line to more than a right angle is the measure of abduction of the thigh on that side and has been named the co-pelvifemoral angle of abduction. Any decrease to less than a right angle is the measure of adduction, with respect to the interfemoral line, and has been designated as the co-pelvifemoral angle of adduction. Normally, abduction is possible to 135 degrees (Fig. 6) and adduction, to 75 degrees (Fig. 7).

Abduction is measured in the following manner. With the patient in the supine position, both lower extremities are abducted to their maximum in the plane of the examining table. The mid-points of the line between the anterior superior iliac spine and the pubic spines are marked on the skin and a line is drawn between these two points. This represents the interfemoral line. From each end of this line, a line is drawn to the mid-point of the knee joint. This represents the mechanical axis of the femur and the angle which this line forms with the interfemoral line is the co-pelvifemoral angle. If it is greater than a right angle, the thigh is in abduction to a degree determined by the amount that the measured angle exceeds a right angle. If the thigh cannot be adducted to the neutral position, the amount that the measured angle of abduction is greater than a right angle is a measure of abduction contracture.

Adduction is measured in the following manner. The opposite leg is abducted to its maximum in the plane of the examining table to fix the pelvis. The thigh is gently adducted until the pelvis can be felt to move or until it can be seen that the angle of abduction of the opposite thigh is diminishing. The angle which the mechanical axis forms with the interfemoral line is the measure of adduction of the examined thigh.

If the thigh cannot be abducted to a right angle, the amount that the measured angle of adduction is less than a right angle is a measure of the adduction contracture.

SUMMARY

The only true measurement of the pelvifemoral relationship is by the determination of the angle between the axis of the femur and a fixed line of pelvic reference.

Four new pelvifemoral angular relationships are described: two in the sagittal plane, the pelvifemoral angles of extension and of flexion; and two in the coronal plane, the co-pelvifemoral angles of abduction and adduction.

In the sagittal plane, motion can be measured by the pelvifemoral angle, the angle which opens downward and backward and is formed by Nélaton's line and the femoral axis. In maximal extension, the pelvifemoral angle of extension is 50 degrees. Any increase in the angle is indicative of a flexion contracture, measured by the amount that the angle exceeds the normal value. In maximum flexion, the pelvifemoral angle of flexion is 125 degrees. The total range of flexion and extension at the hip joint is 75 degrees.

In the coronal plane, motion at the hip joint can be determined by measuring the angle between the mechanical axis and the line drawn on the skin between the two femoral heads.

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Spectrochemical Determination of Trace Metals in Normal Striated Muscle in the Rabbit*

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The use of the back muscles of the rabbit as a convenient, living test tube for the study of corrosion of implanted metal *in vivo* has been described previously [7]. Two of the advantages of this method are a reasonably constant temperature, and the ease of inserting and removing the implants without unduly damaging either them or the tissues.

The present work forms part of a comprehensive investigation of the normal values in this so-called test tube which will eventually include pH and redox potentials. The data to be presented here were obtained during the early part of a study of the corrosion of over forty different alloys and elements *in vivo*. Both a spectrochemical and histological assessment of the behavior of these elements and alloys *in vivo* are planned. Before this can be done, however, the normal trace metal content of rabbit skeletal muscle must be determined with reference to those elements expected to be released by the metallic implants. Since these normal values are of interest to workers in other fields—cancer research [14], enzymology [10], and toxicology [8,13] they are presented separately from the results of the corrosion experiments. Earlier work in corrosion concentrated on reaction of tissue to the metal implant and weight changes of the implant itself [7]. The use of spectrochemical methods to analyze the very small amounts of the constituent elements of an alloy in surrounding tissues was described briefly by Bowden and associates. As suggested by this work [2] and other investigations [12,13,15], emission spectrographic methods can probably be made reasonably quantitative by careful surgical and analytical techniques and thus can be used to measure the corrosion of surgically implanted metal. Spectrography lends itself well to studies of this nature because the method, for many elements, is sensitive to a few parts per million (Table I). In addition, a number of elements can be determined simultaneously when using a relatively small amount of sample. Chemical colorimetric methods frequently require all the available sample for the determination of a single element. However, the sensitivity of the spectrochemical method means, of course, that all reagents must be of the highest purity, the apparatus must be kept free from contamination, and the tissue samples must be removed from the animal without contaminating them with knives and forceps.

SPECTROCHEMICAL METHOD

Several recent papers [6,12,15,16] discussed the application of spectrochemical analysis in detail. Shimp described two procedures for the determination of a number of elements concerned in the present investigation; one a buffer technique using solutions of the samples directly with a buffer, and the other a concentration procedure in which trace quantities are collected into a small precipitate by a mixture of three organic precipitating agents. Koch and his associates reported

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TABLE I

THE SENSITIVITY OF THE PRESENT WORKING CURVES OF THE SPECTROGRAPH FOR SOME OF THE ELEMENTS CONSIDERED

Co .0005%	Mo .0005%
Cr .0003%	Ni .0003%
Fe .0006%	Ti .0003%

TABLE II

1956 ANALYSIS OF ALLEGHENY RIVER WATER. THE ESTIMATED TRACE QUANTITIES ARE CALCULATED ON A VOLUME BASIS (VALUES IN PARTS PER MILLION). THE RESULTS WERE EXPRESSED AS PARTS PER MILLION OF THE ORIGINAL WATER SAMPLE; FOR EXAMPLE, 6 p.p.m. = .000006%

Ag 0.002 p.p.m.	Mn 0.06
Al 0.6	Mo not found
Ba 0.2	Ni 0.02
Co 0.006	Pb 0.002
Cr 0.006	Ti 0.02
Cu 0.06	V 0.002
Fe 0.06	Zr not found

results using these techniques on twenty-one different normal human tissues for the determination of the following elements: aluminum, cadmium, calcium, chromium, cobalt, copper, gallium, iron, lead, magnesium, molybdenum, nickel, tin, titanium, vanadium, and zinc. Tipton and his associates [15,16] reported similar work on twenty-one elements in twenty different tissues, by a different technique.

Very low concentrations were expected in the present work and accordingly the procedure of Shimp was investigated. Considerable difficulty was encountered, however, in obtaining organic reagents sufficiently free from chromium, iron, and nickel as determined by control analyses. In view of this difficulty and our estimate of the time required to do the expected volume of samples by this method, the procedures described by Tipton were explored. These turned out to be sufficiently sensitive to be satisfactory for the present purpose.

SAMPLING OF RABBIT MUSCLE

All rabbits used in the corrosion experiments, and thus those analyzed here, were albino rabbits obtained from one supplier. They were fed on Rockland rabbit ration, carrots, and kale, and were given tap water from the same source to drink. Spectrochemical analysis of the local water revealed a few trace metals in minute concentrations (Table II). These trace amounts occur naturally in this area; figures for other areas are unavailable. The ability of an animal to selectively concentrate the available trace amounts of these elements probably determines the so-called normal concentrations. These may vary from area to area. Two types of control muscle specimens were removed from the animals. The first type came from the erector spinae muscles of animals not involved in the corrosion experiment. The second group consisted of samples removed from the leg muscles of rabbits that had had metal plugs placed in their back muscles. These specimens were used as controls for elements not contained in the metal plug. Spectroscopic analyses of the muscle surrounding the metal plugs were performed; the leg control muscle samples were then used only if the particular elements under investigation were present in concentration of less than 0.1 per cent in the plug. There being no statistically significant difference between the values in these two groups of muscle specimens, they were combined in the presentation of results. In some experiments significant differences occurred between the two types of controls with respect to the elements present in the implants in the backs of the ani-

TABLE III

DETAILS OF OPERATING CONDITIONS OF SPECTROGRAPH USED FOR THE ANALYSIS OF MUSCLE SAMPLES

Spectrograph	ARL 2-meter grating spectrograph Linear dispersion, 5.2. A/mm.
Excitation	ARL Multisource, spark ignited DC arc
Electrode lower upper	Positive polarity, ⅛ inch electrode, ¼ inch deep crater ⅛ inch electrode, both high quality purity
Sample and standards	10 mg. of equal-part mixture of graphite (0.01% Ga_2O_3) and sample ash or standard
Exposure	Burned to completion, about 50-65 seconds Burned 10 seconds at 6 amps. then raised to 12 amps.

TABLE IV

THE LINE PAIRS USED FOR ANALYSIS OF THE ELEMENT AND THE APPROXIMATE CONCENTRATION RANGE COVERED BY THE LINES

	Line	Concentration Range
Ga	2874.2 (filtered)	Internal Standard
Co	3453.5	0.0003—0.01
Co	3417.1	0.01—0.1
Cr	4274.8 (filtered)	0.0003—0.01
Cr	2991.9	0.01—0.1
Fe	3017.6	0.000—0.01
Mo	3170.4	0.0003—0.01
Ni	3414.8	0.0003—0.01
Ni	3080.7	0.01—0.1
Ti	3199.9	0.0004—0.01
Ti	3162.6	0.006—0.1
Zr	3392.0	0.0003—0.01

mals. The results of these experiments will be given in later reports of the corrosion experiment.

The muscle samples were removed immediately after sacrifice of the animals. The sharp edges of broken silica glass fragments were used to cut all layers of tissue except the skin which was cut with a surgical scalpel or scissors. The tissues were handled gently and only with the washed fingers; they were never touched with any metallic instruments. All samples were treated in as nearly the same manner as was possible. It was difficult to keep the sample size constant in all cases but this difficulty will be more significant when it comes to the interpretation of the results of the corrosion experiments. It probably has relatively little effect on the normal values.

The portions of rabbit tissues obtained were at first placed in glass weighing-bottles, weighed, and then quick-frozen until ashed and analyzed. Subsequently, it was found more convenient and economical to put the samples in small preweighed polyethylene bags which were then sealed with scotch tape, reweighed, and quick-frozen as before. The samples were stored in the deepfreeze prior to analysis.

SAMPLE PREPARATION

The sample was placed in ignited and weighed platinum crucibles, and the weight determined. The samples were slowly dried and charred over a low bunsen flame and then placed in a muffle furnace at 450 degrees centigrade. Ashing to

constant weight required twenty-four hours or longer. The samples were removed, weighed, and stored in small plastic vials. Equal weights (about twenty-five milligrams) of sample and high purity graphite powder containing 0.01 per cent gallium oxide were put into a 000 gelatin capsule and mixed by shaking vigorously in a dental amalgamator. Ten milligrams of each sample mixture were weighed and tamped into the craters of special high purity one-eighth of an inch electrodes for burning in the direct current arc.

TABLE V

RESULTS OF SPECTROGRAPHIC ANALYSIS OF THE MUSCLE SAMPLES WITH CALCULATED MEANS AND STANDARD DEVIATIONS. THE MIDDLE COLUMN GIVES THE LINE RANGE COVERED BY THE ANALYSIS

Element	No. of Analyses	Range (*Per cent of Dry Ash*)	Mean (*Per cent*)	Standard Deviation (*Per cent*)
Iron	93	.0006 to > .015	.0039	± .0035
Molybdenum	59 (28 N.L.)	N.L. to .004	.0005	± .0008
Nickel	66 (12 N.L.)	N.L. to .002	.0006	± .0003
Cobalt	99 (94 N.L.)	N.L. to .001	.00003	± .0001
Chromium	33	.0003 to .0027	.0009	± .0005
Titanium	85 (10 N.L.)	N.L. to .01	.001	± .0016
Zirconium	48	N.L.		

N.L. = No line seen; 0.0001% = 1 p.p.m. = 1 microgram per gram dry ash

TABLE VI

THE REPRODUCIBILITY OF THE SPECTROGRAPHIC RESULTS FOR THE MUSCLE SAMPLE IN CONTACT WITH A HAYNES 25 (Co-Cr-Ni-W) METAL CYLINDER. SATISFACTORY REPRODUCIBILITY IS DEMONSTRATED

Element	Concentration Found (*Per cent*)	Average Deviation (*Per cent*)	No. of Runs
Co	0.0019	±0.0006	9
Cr	0.0019	±0.0003	8
Fe	0.0036	±0.0006	9
Mo	0.0010	±0.0003	8
W	Not detected		

SPECTROCHEMICAL ANALYSIS

The operating conditions of the spectrograph are indicated in Table III. The spectrograms of the standards and samples thus obtained were examined visually and notations were made of the lines for the various elements of interest. These lines (Table IV) were marked and read on a Leeds and Northup Recording Microphotometer. The blackness or per cent transmission values for the desired spectrum lines in the standard spectra were determined by microphotometer readings. The values were converted to spectral intensities by a previously prepared emission calibration curve. Frequently, internal standards have been added in spectrographic analysis to compensate for deviations in sample preparation, sample burning, and photographic processing. An intensity ratio between the unknown line and the internal standard line (gallium 2874 Å in this case) was computed.

Such intensity ratios for each concentration were averaged and plotted on logarithmic coordinate paper to give a working curve. In the case of the unknown samples, intensity ratios were similarly computed and applied to the working curve to give the concentration present. Correction for background in the spectra were made where necessary. The per cent transmission values so obtained were corrected for background, and then computed into intensity ratios. Such ratio values were applied to previously prepared working curves to determine the amount of various test elements present.

RESULTS

The analytical data obtained to date are given in Table V and Figure 1 and are expressed as a percentage of the dry ash. The dry ash constituted 0.9 per cent to 1.3 per cent of the wet muscle samples.

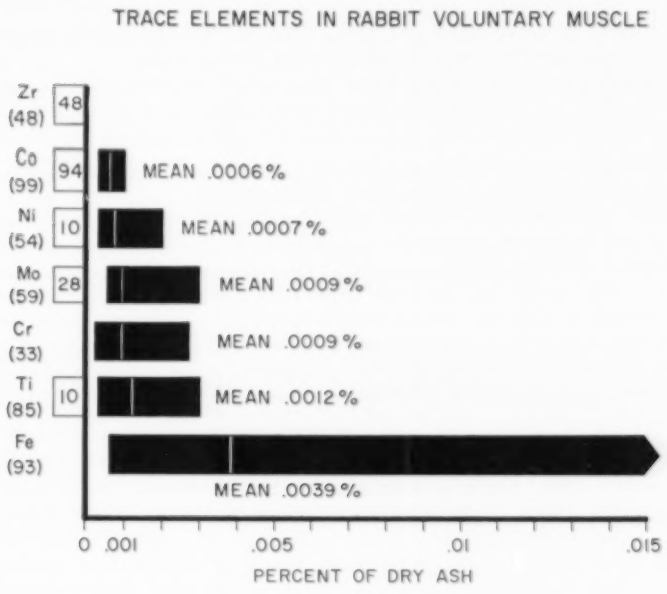

FIGURE I

Diagrammatic presentation of the results of analysis of the rabbit voluntary muscle for certain trace elements. The figures given in the extreme left hand column underneath the appropriate metal symbol represent the total number of samples analyzed. The figures in the boxes to the immediate left of the O-line tell the number of samples in which the appropriate element was not detected. The range of results of the analysis for each element is represented by the total block. The black area represents one standard deviation on each side of the mean which in turn is represented by a thick white line.

One of the samples was analyzed a number of times to determine the reproducibility of the method of analysis. Data from these tests are given in Table VI and demonstrate satisfactory reproducibility.

DISCUSSION OF RESULTS

When it comes to comparing the results of the present study with those of early ones there is a persistent difficulty. Various workers have expressed their results as parts per million, as micrograms per gram, or as a percentage of the sample weight. The sample weight may be the weight of whole wet muscle, dry muscle, or ashed samples. One part per million is equivalent to one microgram

per gram or to 0.0001 per cent. Dry muscle is difficult to define but, if it is dried to constant weight at 100 degrees Fahrenheit, its weight is approximately 25 per cent of the wet weight. The dry ash weight is approximately 1 per cent of the wet weight of the original sample.

In the following discussion of results all other workers' figures have been converted, where possible, to the per cent of dry ash comprising the element under discussion. The large standard deviations recorded are the result of including in the calculations the specimens with no readable line as containing zero per cent of the element. Other workers have expressed their results as mean values calculated only from specimens containing measurable amounts of the element. In order to convey a complete picture the specimens with no detectable element have been included in this study.

Cobalt

In ninety-nine samples analyzed in this study five contained cobalt; .0006 per cent, .0010 per cent, .0006 per cent, .0003 per cent, and .0007 per cent. The mean value of those containing the element was .0006 per cent.

Although Levey and Orten found that cobalt appears *in vivo* as part of vitamin B_{12}, it is not mentioned in recent spectrochemical work on trace elements in cancerous and non-cancerous human tissues [14]. Mitteldorf and Landon, however, found 0.002 parts per million in whole beef muscle which is approximately equivalent to 0.2 parts per million of dry ash or .00002 per cent.

Tipton and associates [15] found eighteen to forty parts per million of cobalt with a mean of twenty-four parts per million in twenty-two specimens of dry ashed human striated muscle analyzed spectrochemically. This is equivalent to 0.0024 per cent of dry ash. In later work Tipton and associates [16] found no detectable cobalt in eighteen human muscle specimens. Koch and associates found no detectable cobalt in human striated muscle. Forbes, Cooper, and Mitchell reported 0.006 parts per million of cobalt in whole human muscle analyzed by the 0-nitrocresol method. This is approximately equivalent to 0.0006 per cent of dry ash.

Iron

One of the difficulties in making accurate iron determinations in skeletal muscle arises from variations in the content of blood. However, this difficulty may be smaller than we first feared.

The mean value for iron in striated muscle in ninety-three specimens was 0.0039 per cent $\pm$ 0.0035 per cent and seemed to run lower than was expected on the basis of other reported work. This difference may be a species variation, that is, rabbit *versus* human, or may be the result of differences in technique. Koch and associates for instance, found an average of 0.6 per cent iron in ashed human striated muscle. Tipton and associates [15,16], using a technique more like the present one, found an average value of 0.031 per cent in eighteen specimens of human muscle. Smith and associates called attention to the fact that if iron is present in a specimen as ferric chloride, loss of iron may result due to the low boiling point of the chloride (315 degrees centigrade). Since the determination of the concentrations of other elements that are of interest is not affected by this possible loss by volatilization, it is believed that the data are quite valid for them. It is of interest that Sheldon and Ramage found iron in a concentration of 0.02 per cent of dry weight in voluntary muscle using spectrographic analysis.

Tietz and associates reported a normal range of iron as less than .00099 per cent in liver, less than .0014 per cent in lung, and less than .0001 per cent in kidney. Their figures are for dry tissues and are approximately twenty-five times higher than they would be for dry ashed tissue.

Nickel

In sixty-five specimens analyzed, nickel was undetectable in twelve and dem-

onstrated in fifty-three, with a mean of 0.0006 per cent of dry ash in all cases.

Tipton and associates [15] found 10 to 146 parts per million with a mean of forty parts per million of dry ash in twenty-two samples of human striated muscle. This is equivalent to 0.004 per cent according to our method and is much higher than even the upper figure in the total distribution of our results (Table III, Fig. 1). In 1956 Tipton and associates [16] in an analysis of eighteen human samples found no nickel lines.

Koch and associates found zero to seven micrograms of nickel per gram of ashed human muscle (0.0007 per cent). This value is in close agreement with our data. Tietz and associates reported two parts per million in normal human liver, three parts per million in lung, and 0.05 parts per million in kidney, all for dry tissues and thus about twenty to twenty-five times higher than they would be if expressed as a percentage of dry ash.

Chromium

Tipton and associates [15] found an average value of eighteen micrograms of chromium per gram of dry ash (0.0018 per cent with a range of .0000 to .0035) in twenty-two samples and in later work [16] six micrograms or 0.0006 per cent in three specimens with one containing a trace and fourteen more having none detected.

Koch and associates do not mention chromium as being present in human muscle. Tietz and associates found from 0.0004 to 0.0049 per cent chromium in dry normal human liver, lung, and kidney.

The thirty-three specimens in this study all contained some chromium with a mean value of 0.0009 per cent of dry ash (±.0005 per cent).

Molybdenum

Tipton and associates [15] found ten to 125 parts per million (0.0001 to 0.0125 per cent) of molybdenum (with a mean of forty parts per million, 0.004 per cent) in twenty-two human striated muscle samples. In a later study [16] they found no detectable molybdenum in eighteen samples.

Koch and associates found a trace in one sample of human striated muscle. In fifty-nine samples examined in this study thirty-one samples contained molybdenum and the mean value for all samples was .0009 per cent (range: .0005 to .003 per cent) of dry ash.

Titanium

In eighty-five specimens examined in this study seventy-four contained titanium and the mean value was .0012 per cent (range: .0003 to .003 per cent) of dry ash. Earlier occasional unexpectedly high values and a wide range (0 to 0.1 per cent) caused us to re-examine our spectrographic tracings for titanium and to choose different lines (Table IV). The values given here are those obtained after recalculation. Further work on this is being done in an effort to explain the occasional high values.

Zirconium and Hafnium

No lines were found for zirconium or hafnium in forty-eight specimens. Other workers do not mention these elements.

Tungsten

No line was found in any of the samples examined for this element.

Aluminum

Samples are being examined for aluminum which has been reported by Kehoe, Cholak, and Story as 0.015 per cent of muscle.

CONCLUSION

It may be concluded that by this method of spectrochemical analysis, rabbit striated muscle has a trace metal content not unlike that found by other workers in human and beef striated muscle.

Cobalt was found in only 5 per cent of ninety-nine samples; zirconium and tungsten were not found. Molybdenum was found in half the samples, nickel in four-fifths, and titanium in four-fifths. Chromium and iron were detected in all.

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Active Shoulder Motion in Complete Deltoid Paralysis

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Isolated deltoid paralysis is the result of injury to the axillary nerve. The natural history of this condition as reflected in the literature is summarized in Table I. Four cases of recovery of shoulder function in the presence of permanent deltoid paralysis are added to those cases previously reported in the literature.

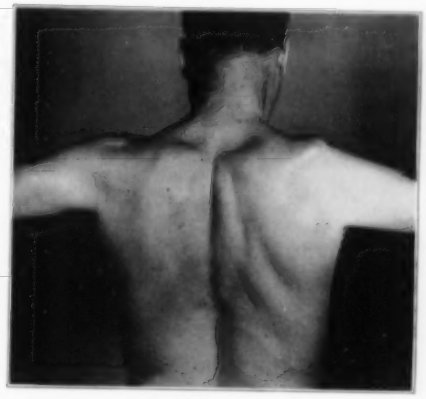

FIG. 1

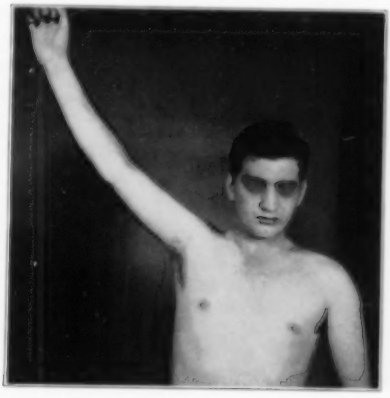

FIG. 2

Fig. 1: Case 1. Eleven months following injury. Active elevation to 90 degrees.

Fig. 2: Case 2. Seven months following axillary-nerve injury. Active elevation of shoulder well beyond 90 degrees.

CASE 1. A man, twenty-nine years old, was injured in a motorcycle accident with initial symptoms suggestive of a rupture of the kidney; however, diagnostic studies failed to substantiate this. An isolated right axillary-nerve paralysis was not diagnosed until approximately one week following the accident when the patient complained of numbness in the region of the deltoid tubercle. Examination revealed paralysis of the deltoid muscle. No history of shoulder dislocation nor roentgenographic evidence of any bone injury could be elicited. The patient's right arm was placed in an abduction splint; physical therapy to preserve shoulder function was initiated. Eleven months following injury neither the deltoid paralysis nor atrophy had improved; however, the patient had recovered the ability to elevate his shoulder well beyond the horizontal (Fig. 1). The abduction splint was discontinued at that time. Following a two-month period of functional activity, the patient maintained a good range of shoulder motion and his only complaint was easy fatigability of the shoulder following prolonged or sustained activity.

Electromyographic studies of the muscles acting in shoulder abduction are shown in Chart I. At follow-up evaluation approximately two and one-half years after injury, the patient stated that he worked as an able seaman and had no complaints referable to his shoulder. Physical examination revealed that the patient had maintained a full range of shoulder motion.

CASE 2. A man, nineteen years old, dislocated the right shoulder and fractured the greater tuberosity of the humerus in an automobile accident. Following reduction of the dislocation, anaesthesia was noted in the region of the deltoid tubercle; one day later paralysis of the deltoid muscle was evident. The patient was treated in a plaster reinforced Velpeau dressing

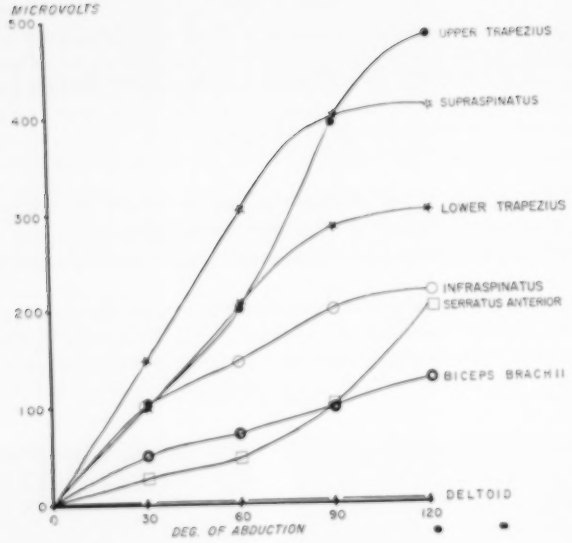

CHART I

Case 1. Electromyographic studies of muscles during active shoulder abduction. Note that there was no activity in the deltoid muscle.

for two weeks and was then placed at bed-rest with his right arm in balanced suspension. Active shoulder motion was started. One month following injury an abduction splint was applied and physical therapy for active shoulder motion was continued. Electromyographic studies of the deltoid muscle three months following injury revealed denervation of the muscle. Six months following dislocation he was able to abduct his shoulder from 90 to 180 degrees and the abduction splint was removed. Seven months following dislocation he was able to abduct his shoulder

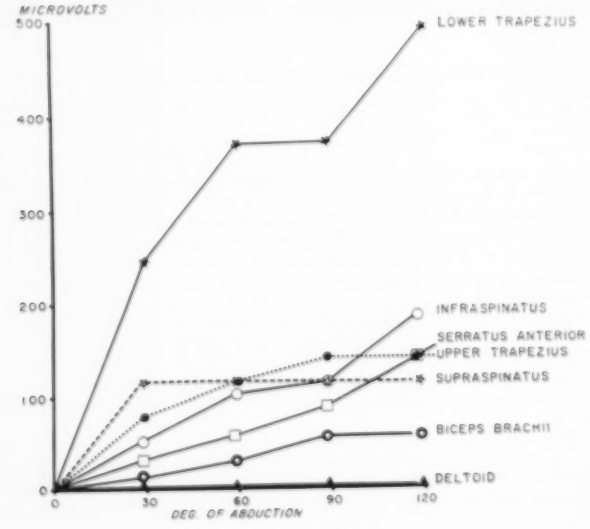

CHART II

Case 2. Electromyographic studies of the muscles acting in shoulder abduction seven months following axillary-nerve injury.

TABLE I

SUMMARY OF THE INCIDENCE AND END RESULT OF INJURY TO THE AXILLARY NERVE

Causative Injury (Closed Injury Only)	Incidence of Deltoid Paralysis	End Result	
		Spontaneous Recovery	Permanent Deltoid Paralysis with Functional Recovery
Shoulder dislocation	Watson-Jones, 5 per cent of cases Murray, 60 per cent of cases	Watson-Jones, 15 of 17 cases	Bunts, 3 cases Pollock, 1 case Dehne and Hall, 1 case
Fracture of greater tuberosity of humerus without dislocation	Dehne, 2 cases	Recovery in both cases	
Direct contusion or violence to shoulder without dislocation			Pollock, 2 cases Bunts, 1 case Staples and Watkins, 2 cases Dehne and Hall, 1 case
Cause not stated			DePalma, 1 case

through a full range of motion with satisfactory muscle power (Fig. 2). He was returned to full duty with the Air Force.

Electromyographic data of the muscles acting in shoulder abduction are given in Chart II.

CASE 3. A man, twenty-three years old, complained of severe pain in his right shoulder radiating down his arm after prolonged driving from Pittsburgh to Fort Benning. The pain subsided after a few days and was followed by numbness extending from the shoulder down toward the forearm. This again lasted only for a few days and made way to progressive weakness of the shoulder. Physical examination revealed deltoid atrophy and weakness, with an area of numbness in the region of the insertion of the deltoid. The weakness progressed to complete paralysis and atrophy of the deltoid, but the patient never lost the ability to abduct his arm fully. His main complaint was difficulty of placing his hand in his pocket because of inability to carry out posterior elevation of his elbow. This patient was not treated by an abduction splint or any supportive device.

CASE 4. A man, twenty-three years old, was injured in a car accident during the Christmas holidays in 1957. The original treatment for a brain injury and fracture of the right clavicle was carried out in a civilian hospital. After the figure-of-eight bandage was removed, he returned to military duty but noted weakness of the right shoulder. This he attributed to lack of active use of the arm. When the weakness did not subside he reported to our institution, where a complete deltoid paralysis associated with anaesthesia in the skin distribution of the axillary nerve was diagnosed. An abduction splint was applied which he wore for only three weeks. Some improvement of function resulted.

When last examined in September 1958 he had complete residual paralysis of the deltoid but could fully elevate his affected arm. His main complaint and difficulty consisted in inability of carrying out posterior elevation of his elbow to bring his hand to his pocket.

DISCUSSION

In none of the patients was recovery of shoulder function associated with a completely normal scapulohumeral rhythm. There was considerable loss of muscle power, particularly for sustained activity. However, each patient gained sufficient function for useful occupation.

It is felt that prolonged splinting of the shoulder in abduction with assistive exercises prevented stretching of the unaffected muscles and enhanced recovery of shoulder function through substitution of the muscles of the rotator cuff. Figure 3 shows the maximum abduction permissible in internal rotation of the arm. At

FIG. 3

Fig. 3: Maximum abduction in internal rotation due to greater tuberosity impinging on the glenoid.

this point, the greater tuberosity impinges upon the upper rim of the glenoid. To permit full abduction from this position, the head of the humerus has to be rotated 180 degrees to a position where the greater tuberosity is opposite the lower rim of the glenoid. This maneuver is accomplished by action of the infraspinatus, which thus is the key to full elevation of the shoulder.

ADDENDUM

It is readily conceded that the opinion advocated in this paper regarding the efficacy of supportive splinting for the treatment of paralyzed muscles is not uncontested. Another school of thought, which disregards protective splinting and relies on electrical stimulation only, has widespread adherence. However, the approach suggested in this report is neither new nor isolated. Fritz Teal, in personal communication, related his personal experiences with two patients with isolated and permanent deltoid paralysis, each of whom recovered with practically full shoulder motion after prolonged treatment in an abduction splint. J. L. Goldner believes in the efficacy of protective splinting but feels that this can be accomplished by a sling reinforced with a piece of rubber tubing as effectively as by the use of a complicated brace.

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Fracture-Dislocation of the Ankle

An Unusual Cause of Failure of Reduction: A Case Report

BY THOMAS F. PARRISH, M.D., NASHVILLE, TENNESSEE

From the Orthopaedic Section, Vanderbilt University Hospital, Nashville

The tibialis posterior tendon has been mentioned as one cause of inability to reduce lateral fracture-dislocations of the ankle joint. Coonrad and Bugg reported two cases in which the tendon slipped into the ankle joint between the talus and medial malleolus and thus blocked efforts at closed reduction. Böhler reported one patient in whom the tibialis posterior tendon was found, at the time of surgery, to be caught between the tibia and fibula. The following case report is an even more unusual cause of failure of closed reduction.

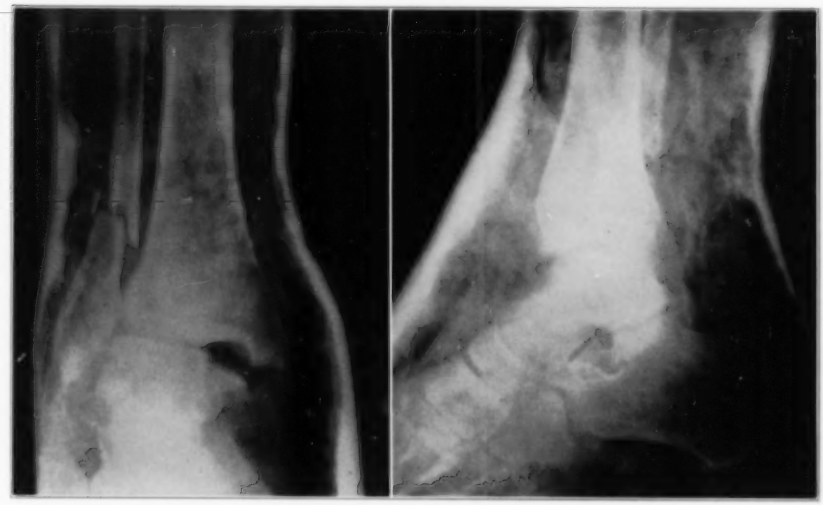

FIG. 1-A FIG. 1-B

Anteroposterior and lateral roentgenograms of the right ankle showing fracture of the medial malleolus and the fibula, the tibiofibular diastasis, and the lateral displacement of the talus.

A white, male laborer, forty-two years old, was seen in consultation four days after sustaining an open lateral fracture-dislocation of the ankle joint. The injury was the result of the patient's jumping approximately four feet from the steam roller he was operating when it went out of control going downhill. He struck the asphalt pavement with a twisting force to the right ankle. The attending physician debrided the wounds, reduced the dislocation as well as possible, and applied a plaster cast after which the first roentgenograms were made (Figs. 1-A and 1-B). It is apparent from examining them that the talus was still slightly displaced laterally in the ankle joint. Seven days after the initial injury, with the patient under general anaesthesia, the plaster cast was removed and a transverse open wound was found, extending from the anterior border of the anterior tibial tendon, across the medial malleolus, and ending over the Achilles tendon. Both tendons were exposed on their medial aspect. The wound was clean, without evidence of infection, and the small fragments of the medial malleolus were excised. Pushing the talus into its normal articulation with the medial malleolus could only be done with strong pressure. It then became apparent that the posterior tibial tendon was not in its normal groove behind the medial malleolus. The talus was then redislocated laterally and the posterior tibial tendon was found to have been carried with the talus as it moved laterally and then to have passed anteriorly between the tibia and fibula, this

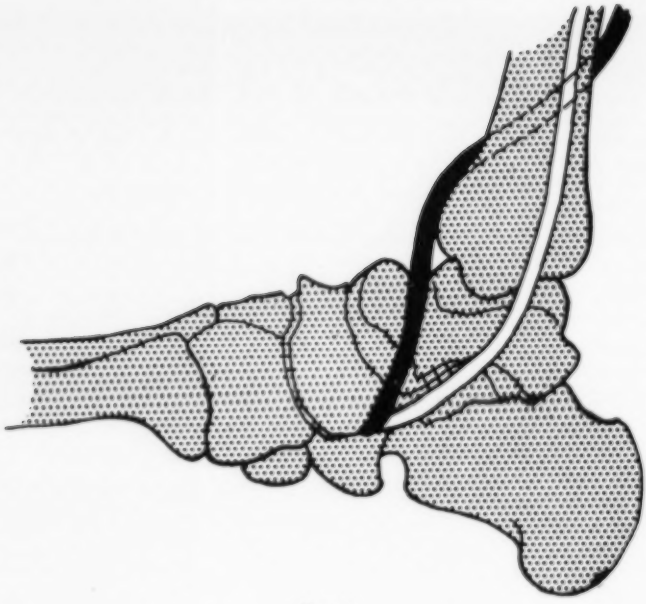

FIG. 2

Schematic drawing showing, in black, the location of the posterior tibial tendon at the time of surgery.

FIG. 3-A FIG. 3-B

Anteroposterior and lateral roentgenograms of the right ankle made ten months after injury showing slight lateral displacement of the talus.

being possible because there was complete diastasis. The posterior tibial tendon was found anteriorly lying on the tibia and across the neck of the talus (Fig. 2). While the talus was dislocated laterally, the posterior tibial tendon was pulled back between the tibia and fibula. As the talus was reduced into the ankle joint, the posterior tibial tendon was brought posteriorly and medially where it promptly fell into its normal position behind the medial malleolus. Reduction of the talus was then easily maintained and the wound thoroughly debrided and irrigated. The deltoid ligament was sutured to the remaining stump of the medial malleolus and the wound was loosely closed.

The patient was last examined ten months after the injury. The wound on the medial aspect of his ankle was well healed. There never had been any evidence of postoperative infection and the wound healed promptly after the delayed primary closure. The heel cord exhibited shortening, with dorsiflexion to 90 degrees. Plantar flexion was complete. There was generalized stiffness of the foot with 5 to 10 degrees of motion in the subastragalar joint. The functional result was good and the patient had already resumed his activities as a laborer with a highway construction crew. However, he did have some discomfort in the foot when walking on irregular surfaces; there was also some discomfort after walking one mile on regular surfaces. Roentgenograms made at the last examination revealed some widening of the ankle mortise and slight lateral displacement of the talus. Clinically, the talus was stable within the joint (Figs. 3-A and 3-B).

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A Hip-Nailing Ruler

BY ALBERT L. BERNDT, M.D., PORTSMOUTH, OHIO

In the fixation of femoral-neck fracture by nailing there arises a minor but constant problem: What length of nail should be used?

Several methods of determining the correct nail length are in use; however, each has a disadvantage. Roentgenographic measurement of the properly placed guide pin is not accurate because of the distortion produced by projection. The calibrated pin is hard to read; the scorings weaken the pin and they increase the chance of the point of the nail catching on a groove. Measurement of the protruding part of the pin may lead to trouble if pins of various lengths are in the instrument set. Reading is made difficult by the fine lines and narrow calibrations of the six-inch stainless-steel ruler usually found in the instrument sets. Lastly, this method necessitates mental subtraction that is not performed too well in the operating room.

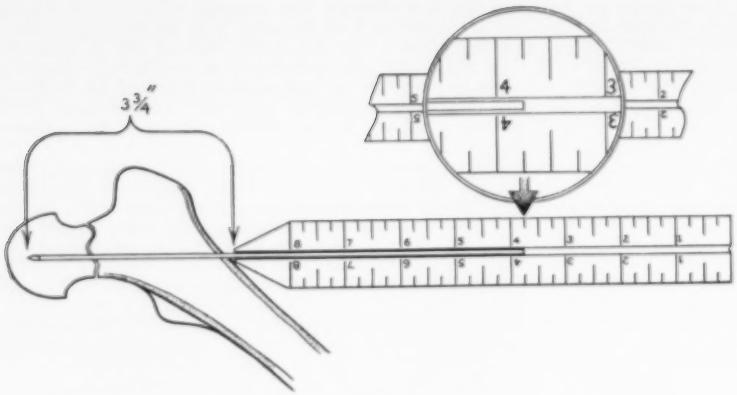

FIG. 1

The following method, incorporating the use of an especially devised ruler, is offered to eliminate the objections previously listed.

The ruler is made of anodized aluminum, nine inches by one and one-quarter inches. One end is tapered to prevent the ruler from being used backward. A groove extends along the mid-line from end to end. Scoring is indented and printed to increase legibility through blood film. Calibration is at one-quarter-inch intervals to correspond to the available lengths of nails. Numbering is toward the bone, not away from it as in other rulers.

The ruler is used as follows:

1. For a guide pin, use only a Steinmann pin measuring nine inches by three thirty-seconds of an inch.

2. Place the ruler, with the tapered end toward the femur, so that the guide pin lies in the groove of the ruler. Slide the ruler toward the bone until the tip of the ruler touches the cortex. Read the scale at the end of the guide pin (Fig. 1).

3. The indicated length is correct for all nails whose butts lie flush with the cortex (for example, Jewett, Neufeld, and Moore) and for the Smith-Petersen nail when used without a plate. If a Thornton plate is to be used with a Smith-Petersen nail, add one-quarter of an inch to the indicated length to compensate for the offset of the plate.

In addition to the hip-nailing feature of the ruler, the reverse side carries conventional ruling in centimeters and inches. Punched holes, for measuring the diameter of Steinmann pins and Kirschner wires, are also provided.

Proceedings

THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

The Twenty-sixth Annual Meeting of The American Academy of Orthopaedic Surgeons was held at the Palmer House, Chicago, January 24 through 29, 1959, under the Presidency of Dr. H. Relton McCarroll.

At the Second Executive Session, the new President, Dr. Harold A. Sofield, Oak Park, Illinois, was inducted into office. The following officers and committeemen were elected:

President-Elect: Hugh Smith, M.D., Memphis, Tennessee;
Vice-President: Robert Lee Patterson, Jr., M.D., New York, N. Y.;
Treasurer: Carroll B. Larson, M.D., Iowa City, Iowa;
Secretary: Clinton L. Compere, M.D., Chicago, Illinois;
Librarian-Historian: Albert C. Schmidt, M.D., Milwaukee, Wisconsin.
Executive Committee:
William T. Green, M.D., Boston, Massachusetts;
H. Relton McCarroll, M.D., St. Louis, Missouri.
Junior Members of the Executive Committee:
Robert W. Bailey, M.D., Ann Arbor, Michigan;
Vernon L. Nickel, M.D., Los Angeles, California.
Member of the Membership Committee: Francis E. West, M.D., San Diego, California.
Member of Committee on Scientific Investigation: Joseph M. Janes, M.D., Rochester, Minnesota.
Member of Committee on Public Relations: Claude N. Lambert, M.D., Chicago, Illinois.
Member of Committee on Instructional Courses: Francis J. Cox, M.D., San Francisco, California.
Member of Committee on Audio-Visual Education: Vernon C. Turner, M.D., Evanston, Illinois.

Dr. Don H. O'Donoghue was appointed Chairman of the Program Committee.

The next Annual Meeting of The American Academy of Orthopaedic Surgeons will be held in Chicago, Illinois, January 23 through 28, 1960.

Summaries of papers presented at the Scientific Sessions follow:

Combined Program of the Orthopaedic Research Society and the American Academy of Orthopaedic Surgeons

Use of Radio-Active Sodium to Determine Bone Viability. Mr. Patrick G. Laing, F.R.C.S.[1] and Dr. Albert B. Ferguson, Jr.[2] said that avascular necrosis is an important complication in fracture of the femoral neck and dislocation of the hip. They stated that four methods are currently available for its diagnosis and presented a fifth one:

1. Radiographs may show apparent increased density of avascular bone three to four weeks after injury. 2. Punch biopsy may reveal avascular necrosis as early as two to three weeks after injury. 3. Phlebographic techniques, which depend on the injection of a radiopaque dye into the bone, may reveal impaired drainage through the veins by radiography. 4. After an intravenous injection of the radiophosphorus, the uptake of P^{32} by the femoral head may be studied by one of two methods. After ashing, the radioactivity of a small piece of the femoral head may be compared with that of a piece of normal bone. This takes time and the specimen may be contaminated by radioactive blood. A probe Geiger counter may be inserted into the femoral head and radiation from surrounding bone counted. Since P^{32} gives off only beta radiation, only one to two millimeters of bone can be counted. 5. The method depends on the rate of clearance of Na^{24} from the femoral head after injection by means of a special metal syringe and cannulated drill. Na^{24} gives off both beta and gamma radiation. The latter can be counted from the body surface. The method was first used experimentally on fifteen dogs, in which the right hip of each was deprived of its blood supply. A dosage of six microcuries was injected into the femoral head, and counts were taken over the hip joint. Totally avascular heads gave clearance rates of between 0 and 5 per cent of the original dose. Partially devascular heads gave clearances of between 10 and 15 per cent. Vascular heads gave clearances of between 20 and 50 per cent. Na^{24} clearance studies were performed on fifteen human adults: nine patients with fracture of the femoral neck, five with dislocated hips, and one with spontaneous avascular necrosis. The operation is performed under roentgenographic control. A cannulated drill is used to drill a hole in the femoral head into which the syringe is screwed. The Na^{24} is deposited in the end of the drilled hole. After the syringe is

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removed, a scintillation counter is placed over the hip joint. This process adds only twenty minutes to the operation. When the head is avascular, the clearance is between 0 and 5 per cent. With this information the surgeon can plan his surgery more accurately. The method is of value in obtaining a prognosis in dislocated hips and enables early attempts to be made to salvage an avascular femoral head.

Injection Studies of Bone Transplants. Dr. Leslie Hammack [3] and Dr. W. F. Enneking [4] carried out this investigation to determine the correlation between the rate of vascularization of homogenous-bone transplants and the inflammatory response evoked by these transplants. Animals were prepared with an autogenous-bone transplant in one extremity and, simultaneously, a homogenous-bone transplant in the other extremity. At intervals ranging from twenty-four hours to twelve days, the aorta was cannulated and the extremities perfused with a heparinized solution of India ink. Full-length sagittal sections of the extremities were then prepared for histological study. The study showed that in rats, initially, the rate of vascularization of homogenous and autogenous-bone transplants is the same, and that the appearance of periosteal new bone surviving from the transplants is the same. This periosteal proliferation coincides, in regard to time, with the vascularization. The inflammatory response to the homogenous-bone transplant appears at about the tenth day after transplantation and coincident with this inflammatory reaction there is first a choking off of the vascular supply to the transplant and then necrosis of the early periosteal proliferations. Studies of the earlier specimen suggest that the vessels from the host which invade the transplant unite with previously existing vessels in the transplant rather than slowly invading the previous Haversian systems.

This study suggests that the inflammatory response evoked by homogenous-bone transplants causes obliteration of an already established vascular supply and subsequent necrosis of surviving proliferations from the transplant.

Amino-Acid Chromatography and Transaminase Activity in Denervation Atrophy. Dr. P. J. Harman [5], Dr. J. L. Magnani [6], Dr. S. D. Sanwal [7], and Dr. W. A. L. Thompson [8] reported a study of the free amino acids and their related enzymes in normal muscle and in muscle undergoing denervation atrophy in the gastrocnemius-soleus muscles of rats and mice after surgical division of the sciatic nerve in one extremity. The determinations made were: (1) the water content by comparison of fresh muscle weights with weights of the same muscle after desiccation to a constant weight; (2) the content of free amino acids as determined by extraction with alcohol followed by separation, identification, and the measuring of the concentrations by paper chromatography and colorimetry; (3) the glutamic-oxaloacetic and glutamic-pyruvic transaminases activities by chromatography and spectrophotometry. The average weight-loss of the denervated muscle was 60 per cent in the rats and 56.5 per cent in the mice at the end of three weeks, but the wet-weight-dry-weight ratios were not appreciably changed during atrophy, indicating that dehydration is not a significant factor in the weight loss that characterizes denervation atrophy. Of the free amino acids only the concentration of alanine was strikingly altered during denervation. There was no change in transaminase activity per unit of dry weight in either the rat or mouse muscle even when atrophy had advanced to the point where more than half of the original muscle-weight was lost. However, when appropriate corrections were applied it appeared that the glutamic-pyruvic activity in rat muscle and the glutamic-oxaloacetic activity in both rat and mouse muscle was increased after atrophy had progressed for two to three weeks. It was suggested that the study of free alanine and of the glutamic-alanine ratio might prove useful in the study of muscle disease. The elevated transaminase level noted in atrophy was likened to similar change in enzyme activity reported in muscle dystrophy.

The Effect of Particle Size of the Heterogenous-Bone Transplant on the Host Tissue Vascular Reaction. Dr. Kirk J. Anderson [9], Joan Schmidt, M.S. [10], and Dr. John F. LeCocq [11] conducted an experiment to evaluate the process of vascularization of both large and small-particle size calf-bone heterografts. Various types of bone fragments, one to three millimeters in the longest dimension, (adult cortical and cancellous, and fetal cortical) were used, including relatively fresh bone and bone which had been stored in bovine plasma or physiological saline solution for from six weeks to nine months. The small-particle size grafts were prepared

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as a conglomerate paste and also stored in plasma or saline solution. Fresh, large-particle, autogenous, cancellous bone was utilized as a comparison material.

The grafts were implanted in the anterior chamber of the eye of an albino rat. Three-dimensional visualization of the vascular bed of the host and its relationship to the bone was accomplished by ante-mortem injection with Prussian blue, and by clearing the specimen by the Spalteholz technique.

Observations revealed that the cancellous autogenous-bone implant was well penetrated by host vessels within one week. There was no concentration of vessels at the peripheral boundary of the bone, indicating no particular tissue barrier to penetration. The character of the vascularization did not materially change at weekly intervals up to the terminal-sacrifice period of twenty weeks. Histological sections revealed injected vessels extending into the trabecular pattern of both donor bone and new bone. Penetration of the Haversian canal was rarely observed.

The calf-bone heterograft of small-particle size (0.1 to 0.3 millimeter in the longest dimension) was penetrated and vascularized in a manner similar to the autogenous-bone graft but the heterogenous-bone graft induced an inflammatory reaction characterized by a hyper-vascularity of the marginal corneal vessels up to the third week. The caliber of the vessels penetrating the bone enlarged until the tenth week, after which these vessels underwent contraction.

The heterogenous-bone graft of large-particle size never showed any appreciable vascularization, as far as deep penetration was concerned, up to twenty weeks. A dense collection of vessels of the sinusoidal type would accumulate around the periphery of the graft extending over its surface. After three weeks, small capillary-like vessels with blunt endings seemed to stem from the surface vessels and attempt to penetrate the deeper aspects of the bone for a fraction of a millimeter. This type of graft did not incite any degree of inflammatory vascular response on the part of the host.

There was no appreciable difference in the vascular response in the host to the various types of calf bone, whether implanted in the fresh state or after preservation in bovine plasma or saline solution.

It was concluded that the anterior chamber of the eye is ideal for visualizing vascularization in the host of bone-graft material. The capacity of small-particle size bone to induce vascularization would appear to be related to its physical-chemical properties. The process of vascularization and success of the bone graft are not synonymous but each is a phenomenon that obeys laws of its own.

An Experimental Approach to the Etiology of Congenital Dislocation of the Hip. Dr. William S. Smith[12], Dr. Carl R. Coleman[13], Dr. Richard F. Slager[14], and Dr. Melvin Olix[15] stated that an experimental approach to the problem of the etiology of congenital dislocation of the hip has been notably absent. The authors investigated the effects of varying the developmental circumstances of a weight-bearing ball-and-socket joint in a young, growing animal including:

1. The sequelae of experimental dislocation of a weight-bearing ball-and-socket joint;
2. The effect of local environmental influences on acetabular development;
3. The effect of early alteration of the acetabulum on the integrity of the hip joint.

As an outgrowth of the experiments on animals, the following were investigated:

1. The birth presentation of ninety patients with congenital dislocation of the hip;

2. The magnitude and direction of force required to dislocate the hip in cadavera of infants.

As a result of these studies, the authors believe that any theory of the etiology of congenital dislocation of the hip should take into account the following clinical and experimental evidence not previously documented:

1. The incidence of breech presentation of ninety patients with congenital dislocation of the hip was 25.5 per cent. The incidence of breech presentation in the normal population is 3.4 per cent.

2. Relaxation of the supporting structures of the hip and subluxation can be produced consistently in cadavera of infants by the application of as little as three pounds of force in any direction.

3. The hip joint cannot be experimentally dislocated in cadavera of infants without tearing the capsule.

4. As a consequence of experimental dislocation of the hip in four-week-old puppies, progressive acetabular dysplasia and torsional changes in the relationship of the femoral head and neck to the shaft were observed.

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13. Ohio State University Hospital, Columbus 10, Ohio
14. Ohio State University Hospital, Columbus 10, Ohio
15. Ohio State University Hospital, Columbus 10, Ohio

5. The development of the acetabulum is dependent upon the shape or geometric characteristics of the structure placed within it during the growth phase.

6. Alteration of the acetabulum by surgically producing a shallow socket in dogs soon after birth does not cause dislocation of the hip, but merely results in a shallow socket—resembling the acetabulum—which occurs clinically in subluxation.

7. Alteration of the acetabulum in dogs soon after birth by a surgically produced shallow socket together with section of the ligamentum teres may result in dislocation during the subsequent growth phase.

Delayed Bone Transplants. (An Experimental Study.) Dr. Robert S. Siffert [16] and Dr. Ernest S. Barash [17] said that although many clinical and laboratory experiments have been performed in an attempt to discover or develop the most suitable form of bone for storage and transplantation, little attention has been paid to the role of the graft bed. Their study was designed to investigate a possible method whereby the bed might be rendered more receptive to bone transplants.

In the first operation a defect (0.5 centimeter) was made at the junction of the middle and lower thirds of the left ulna of a rabbit and the skin was closed. At a second operation, six days later, two equal portions of iliac cancellous bone were removed. One fragment was transplanted into a freshly prepared defect in the right ulna as a control, and the other transplanted into the early granulation and mesenchymal-tissue bed of the original operative site in the left ulna. The animals were sacrificed at varying intervals during the first two weeks after operation. The experiment was not a comprehensive study of the gross rate of healing across the bone defect, but an attempt to study the early phase of graft incorporation. In all, there were twenty-four autogenous, seven homogenous, and seven heterogenous-bone transplants.

On the control side, at the end of one week in the fresh defect, the transplant was necrotic, surrounded by hemorrhagic areas and early granulation tissues in the bed. After one week of residence in the delayed bed, however, the transplant had made contact with new bone which had invaded the bed from the bone ends, with ingrowth of osteogenic tissues into the graft, surrounding the trabeculae, and with apparent survival of graft elements. Proper timing seemed important. When the transplantation was performed before six days, the bed consisted of hematoma and inflammatory tissue, whereas when transplantation was done after ten days, the bed seemed to have reached too great a degree of maturity, with the result that the graft was not incorporated. Although early donor-host bonding was not as rapid in the homogenous and heterogenous-bone series as it was in the autogenous-bone series, the delayed grafts uniformly had made good contacts and were invaded while fresh grafts lay dormant in the granulation-tissue bed.

Although further work is indicated to study the mechanism of early incorporation in greater detail and its relationship to gross bone-defect healing, these experiments indicate that delayed bone transplantation greatly enhances the receptivity of the graft bed to autogenous, homogenous, and, to a lesser degree, heterogenous-bone transplants.

The American Academy of Orthopaedic Surgeons

Sunday, January 25

Fragmentation, Realignment, and Intramedullary Rod Fixation of Deformities of the Long Bones in Children. A Ten-Year Appraisal. Dr. Harold A. Sofield [18] and Dr. Edward A. Millar [19] presented their experiences gained with this procedure at the Chicago Unit, Shriners' Hospital for Crippled Children. Since the original procedure was performed more than a decade ago, 117 long bones in fifty-two patients were subjected to this operation as a primary procedure.

This procedure was performed in:

1. Osteogenesis imperfecta. (Twenty-two patients; eighty primary procedures.) Experience suggested that the technique was most applicable in the management of these cases. The frequency of fractures with the associated progressive deformities was reduced. Existing malalignment was improved. Since the limbs were less painful and more stable, the child could use them to a greater degree. It was usually necessary to put in longer rods as growth progressed.

2. Congenital pseudarthrosis. (Five patients; three tibiae, one radius, one fibula.) The results here, while early, were encouraging. Intact bone was attained and maintained in all cases. There was minimal follow-up of four years.

3. Rachitic-like deformities. (Six patients; nine femora, two tibiae.) This technique permitted correction at several levels with good control of alignment by the intramedullary rod. Correction was thus greater than that obtained with an isolated osteotomy.

4. Fibrous dysplasia. (Three patients; three femora, one tibia.) The technique was somewhat complicated since a nail traversing the intramedullary rod to provide support for the

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femoral neck was used. The results justified these technical difficulties as the progression of the deformity was arrested.

5. Congenital shortening of bone. (Thirteen patients; four femora and ten tibiae.) In this group the use of the intramedullary rod was experimental. The objective was to stimulate growth by an increased metaphyseal blood supply and improved alignment. These results were encouraging but not conclusive.

The complications were relatively few. Two deaths occurred, one of which was owing to aspiration. Three infections, all of which subsequently healed, occurred in 188 surgical procedures. There were no non-unions and no permanent vascular or nerve injury.

The Cavo-Varus Foot. Dr. S. Benjamin Fowler[20], Dr. Arthur L. Brooks[21], and Dr. Thomas F. Parrish[22] presented a preliminary report on a new method for correction of cavo-varus deformity. They feel that the deformity occurs primarily in the presence of paresis or paralysis of the flexor hallucis brevis and of the interosseous muscles of the foot. Of the extrinsic muscles of the leg, anterior tibial weakness appears to be a deforming factor but routine muscle charts of patients with anterior poliomyelitis give no indication of the paralytic pattern producing this deformity. It is contended that the primary deformity is a drop of the first metatarsal head with pronation of the fore part of the foot and that varus deformity of the heel is secondary to, and always less than, the degree of pronation of the fore part of the foot.

Correction of the deformity has been obtained by vertical osteotomy of the cuneiform. The osteotomy site is opened inferiorly and held by a triangular wedge of autogenous bone based inferiorly. This elongates and elevates the medial ray of the foot. In addition to this, plantar fasciotomy is generally necessary, and it is further recommended that the anterior tibial tendon be transposed to the dorsum of the first metatarsal head. Evidence is presented that in the flexible cavo-varus foot where satisfactory extrinsic muscle balance is present, this procedure will correct the deformity although final evaluation of the procedure must await long-term follow-up of these skeletally immature feet.

Anorganic Bone-Grafting. Dr. Lloyd A. Hurley[23], Dr. Francis G. Zeier[24], and Dr. Frank E. Stinchfield[25] said that the development of anorganic bone was based on the hypothesis that the biological failure of certain bone grafts is due to the response evoked by organic constituents—proteins, fats, and mucopolysaccharides. Working on this basis, extraction of these fractions was accomplished by exposing the bone to the action of ethylenediamine, a strong alkaline organic solvent. Ethylenediamine was cycled over the bone in a Soxhlet extraction apparatus using the method of Williams and Irvine, as modified by Losee.

Animal experiments conducted at the Naval Medical Research Institute, Bethesda, Maryland, over a period of four years demonstrated that this material was accepted by the host without localized inflammatory reaction. The marrow-vascular spaces of the anorganic implants were rapidly invaded by osteogenic tissue from the host.

This report presents a preliminary account of experience with anorganic bone in surgical procedures on 149 patients, who were followed from five months to two years. The anorganic bone was used in:

Five femoral-neck fractures fixed with the Smith-Petersen nail (experimental group); nine bone defects, including bone cysts and enchondroma; nine reconstructive procedures, such as arthrodesis; thirty spine fusions, from the fifth lumbar to the first sacral and from the fourth lumbar to the first sacral; six cranioplasties; and ninety cranial burr holes (300 implants).

Anorganic bone was employed only in procedures where it was in contact with a large, raw, osseous surface, which was capable of producing an osteogenic response of sufficient degree to engulf and remodel the graft. Basically, it was intended that the implants serve as a temporary scaffolding or histological template. Because of its extreme fragility, anorganic bone was not used when the graft was employed for internal fixation.

When properly handled, anorganic bone has been well tolerated by the host and rapidly incorporated in reparative callus at an early stage. Except for one patient, there were no untoward responses in this series of cases. If the material is too fine, a non-specific inflammatory response may be anticipated.

The results in both animal and clinical investigations have demonstrated that the unfavorable host response to the heterogenous-bone graft may be avoided by extraction of the organic matrix. It is too early to draw definite conclusions concerning the clinical value of anorganic bone. Studies of the long-term fate of this material, when transplanted, are definitely in order and are now in progress.

20. 1919 Hayes Street, Nashville 4, Tennessee
21. Vanderbilt University Hospital, Nashville 5, Tennessee
22. 1921 Broad Street, Nashville 4, Tennessee
23. Columbia-Presbyterian Medical Center, New York, N. Y.
24. Welborn Clinic, Evansville, Indiana
25. Columbia-Presbyterian Medical Center, New York, N. Y.

Anorganic bone should be employed only in osseous defects which would be expected to reconstitute themselves, provided fibrous tissue were prevented from entering the empty space.

Monday, January 26

Gastrocnemius Muscle Recession (Silfverskiold Operation) for Spastic Equinus in Cerebral Palsy. Dr. Carroll M. Silver [26] and Dr. Stanley D. Simon [27] presented the results of an eleven-year study (1947-1958) of cerebral palsy in 525 children at the Meeting Street School in Providence, Rhode Island. Two hundred and fifty-three operative procedures were performed on the lower extremities of eighty-eight (17 per cent) patients.

Spastic equinus is the most common deformity of the lower extremities in cerebral palsy. Silfverskiold, in 1924, described the gastrocnemius-recession procedure for non-fixed spastic equinus deformity.

A total of 110 gastrocnemius-recession operations, with section of part or all of the tibial motor nerve to the gastrocnemius, were performed by the authors between 1947 and 1958. Follow-up studies, up to ten years postoperatively, revealed only five recurrences. The reason for this small series of failures was analyzed by the authors.

Treatment of Cancer of the Extremities by Perfusion with Chemotherapeutic Agents. Dr. Oscar Creech, Jr. [28], Dr. Edward T. Krementz [29], Dr. Jack K. Wickstrom [30], and Dr. Robert F. Ryan [31] said that a technique of isolating and perfusing tumor-bearing areas has been developed to avoid systemic toxic effects and, at the same time, bring maximum concentrations of chemotherapeutic agents into contact with malignant neoplasms. Thirty-seven patients with malignant tumors involving the upper and lower extremities were perfused with nitrogen mustard, phenylalanine mustard, thio-triethylenephosphoramide, actinomycin D, or 5-fluorouracil. The tumors included seventeen malignant melanomata, fourteen soft-tissue sarcomata, three osteogenic sarcomata, two metastatic adenocarcinomata, and one primary epidermoid carcinoma. The isolation achieved with the use of a proximal tourniquet was adequate to prevent generalized toxic effects and to avoid injury to the defense mechanisms of the host. In an isolated perfusion of the leg through the common femoral artery, dosages up to 0.8 milligram per kilogram of body weight of nitrogen mustard, 1.5 milligrams per kilogram of body weight of phenylalanine mustard, 0.8 milligram per kilogram of body weight of thio-triethylenephosphoramide, 50 micrograms per kilogram of body weight of actinomycin D, and 20 milligrams per kilogram of body weight of 5-fluorouracil were used. The local toxic effects were minimal, primarily consisting of early oedema or the late brawny induration similar to that seen following roentgen therapy. While these doses might be tolerated systematically, when confined to the leg they represent a dosage of six to eight times the usual systemic body dose.

Of the seventeen patients with malignant melanomata, thirteen were treated for palliation and of these: two died; the disease is considered quiescent in eight; and recurrent in three. Of the four patients whose treatment was an adjuvant to conventional surgical therapy, one had local recurrence and the other three remained controlled. In the seventeen patients with sarcomata, thirteen were treated for palliation: five of these are dead; three patients have had responses followed by recurrence; three are controlled; and two had quiescent disease. Of the four patients whose treatment was an adjuvant to conventional therapy: one patient is dead; one had quiescent disease; and two appear to be controlled. Of the three patients with carcinoma: one patient whose treatment was an adjuvant to conventional therapy remains controlled; and in the two patients treated for palliation it is too soon to evaluate the response. As our first patient was only treated seventeen months ago, the evaluation of these results must be guarded.

The Treatment of Giant-Cell Tumors. Dr. E. W. Johnson, Jr. [32], and Dr. D. C. Dahlin [33], presented an analysis of 116 cases of giant-cell tumor taken from the files of the Mayo Clinic with particular reference to the results of therapy. Many of the patients had received multiple forms of treatment but the series was divided into groups according to the primary treatment. In seventy-one patients treated with curettage, the rate of recurrence after treatment steadily increased for ten years at which time only 40 per cent were free of disease. No recurrences occurred after ten years. Fourteen tumors were treated by primary excision and four additional lesions were excised after failure of curettage and other measures. Sixteen of these had no recurrence. The remaining two had complications due to radiation necrosis and non-union.

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27. 225 Waterman Street, Providence 6, Rhode Island
28. Tulane University School of Medicine, New Orleans 12, Louisiana
29. Tulane University School of Medicine, New Orleans 12, Louisiana
30. Tulane University School of Medicine, New Orleans 12, Louisiana
31. Tulane University School of Medicine, New Orleans 12, Louisiana
32. 200 First Street, S.W., Rochester, Minnesota
33. 200 First Street, S.W., Rochester, Minnesota

Thirteen patients were treated by irradiation alone after biopsy. The tumor was not controlled in a single instance. Radiation was employed at some time in seventy-four of the 116 patients. Although its effects were difficult to evaluate, little justification was found for either preoperative or postoperative roentgen therapy, except for tumors so situated that surgical treatment was impossible. Sixteen patients were treated by primary amputation for various reasons and eighteen others had amputations after failure of other forms of therapy because of either malignant transformation or massive recurrence. Ten sarcomata developed after treatment of tumors which originally were no more anaplastic than those in the rest of the series. There were eighteen giant-cell tumors involving the sacrum, ilium, and vertebra. In these, irradiation seemed somewhat more successful. The authors concluded that early, complete excision including the surrounding shell of bone and fibrous tissue was the treatment of choice and that if the tumors of the sacrum, spine, ilium, skull, and distal portion of the tibia are excluded, 79 per cent of the tumors in this series could have been excised. The authors also stressed the importance of long follow-up (continuous after roentgen therapy and for more than ten years after curettage) in the evaluation of the results of therapy.

Experiments in Immunity in Cancer. Dr. Gordon Murray[34] described his experiments which were designed to explore the possibility of immunity against cancer. This might be in the nature of a specific antigen-antibody response, or an improvement of the primordial type of antibody in the form of properdin.

To look for evidence of such immune reactions or host resistance, horses were injected with aseptic samples of malignant tumors obtained from operating rooms. The gamma globulin fraction of horses' blood was given intravenously to patients. Only those patients in the late metastatic stage of cancer of breast, stomach, or colon, where operations, radiation, hormone therapy, and excision of the ductless glands had failed, were treated. A number of the patients were unable to tolerate sufficient quantities of the immune horse serum. However, when 300 cubic centimeters of the serum was tolerated, there was sufficient improvement in most to suggest the possibility of an immune response.

A Preliminary Report of the Anatomic and Histologic Studies Concerning the Findings and Suggested Pathogenesis of Congenital Equinovarus and Calcaneovalgus Deformities of the New Born. Dr. Ahmed Moshiri[35], Dr. Joseph A. Freiberg[36], and Dr. Benjamin H. Landing[37] reported the roentgenological, anatomical, and histological findings in a still-born infant with equinovarus deformity of the left foot and severe valgus or vertical talus deformity of the right foot. The extrinsic muscles of the foot were carefully dissected free from their origin and from the musculotendinous junctions and their weights compared with those of muscles similarly dissected from two apparently normal feet of a still-born infant. The tibialis anterior, tibialis posterior, and gastrocnemius in the two deformed feet were relatively larger than the same muscles in the normal feet. The peronaeus longus and brevis muscles in the deformed feet were smaller than in the normal. The insertions of the tendons in the two deformed feet were normal.

Histological examination of the various extrinsic muscles of the foot, both in congenitally deformed feet and normal feet, showed a high instance of coiling of the muscle fibers. Although this has previously been reported as an abnormal condition in the feet of a new-born infant, it is probably a normal condition. The nerves of the lower leg and feet of the two congenitally deformed feet appeared normal macroscopically and microscopically.

The authors concluded that the findings were consistent with the view that club-foot is a result from either a genetically determined abnormality of development or from acquired (environmentally influenced) deviations of development, but not in a simple mechanical way. The muscle-weight data reported suggested that the deviations from normal values may represent the results of the malposition rather than the cause.

Recurrent Talipes Equinovarus: An Evaluation of Soft-Tissue Procedures in the Three to Eight Year Age Group. Dr. W. W. Bartels[38] and Dr. Benjamin W. Dromp[39] reviewed the records of the Nebraska Orthopaedic Hospital to evaluate the treatment of 118 consecutive patients with congenital club-foot admitted during the period of 1946 to 1955, inclusive.

This review indicated that seventy-five of these patients underwent surgery as a part of their treatment. Inasmuch as these procedures were mostly for treatment of recurrent talipes equinovarus in patients of the intermediate-age group (three to eight years old) the surgery was reviewed to evaluate the soft-tissue procedures performed to treat varus deformity

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36. 2939 Vernon Place, Cincinnati 19, Ohio
37. Children's Hospital, Cincinnati 29, Ohio
38. Nebraska Orthopaedic Hospital, Lincoln, Nebraska
39. Wayne State University College of Medicine, Detroit, Michigan

and inversion of the fore part of the foot. For this indication alone, thirty-five patients underwent forty-six soft-tissue procedures; twenty-one, Brockman procedures; twenty, anterior tibialis tendon transplantations; and five, anterior tibialis tendon transplantations combined with medial capsulotomies. In addition, posterior capsulotomy and Achilles-tendon lengthening procedures were performed as indicated.

There was sufficient follow-up to permit grading of results in thirty-one of these patients. These were found to be:

1. Seventy-one per cent of the patients on whom Brockman procedure was performed had good or fair results.

2. Eighty per cent of the patients who underwent anterior tibialis tendon transplantation with medial capsulotomy had good results.

3. Eighty-five per cent of the patients upon whom anterior tibialis tendon transplantation alone was performed had good or fair results.

Plantar Dissection. An Operation to Release the Soft Tissues in Recurrent or Recalcitrant Talipes Equinovarus. Dr. Frederic C. Bost (deceased), Dr. Edwin R. Schottstaedt [40], and Dr. Loren J. Larsen [41] described in detail the operation used at the San Francisco Unit of the Shriners' Hospital for Crippled Children for the treatment of resistant club-foot. This operation was used only after failure of conservative therapy according to the method of Kite. First performed in 1946 the operation embodies the principles laid down by Ober, Steindler, and Garceau and resembles closely the operation described by Brockman in 1930. Through the medial incision described by Henry, all the ligamentous structures related to the articulations of the navicular, talus, and calcaneus are divided or released along with the posterior tibial tendon and many of the ligaments of the cuneiform-metatarsal joints. When indicated, a heel-cord lengthening and posterior capsulotomy are performed through an extension of the same incision. Transplantation of the anterior tibial tendon is also performed at the same procedure, if considered necessary. Gentle manipulative correction of the deformity is performed at the conclusion of the operation and the correction completed after the wound has healed, using repeated changes of plaster cast or wedging casts. In the period of from 1946 through 1953, 168 operations (forty-nine bilateral) on 119 patients were performed. The results of seventy operations in fifty-one patients who had reached the age of thirteen or older, with a follow-up of two to twelve years, were reported. The results were graded as satisfactory in 64 per cent. Triple arthrodesis was subsequently performed on most of the unsatisfactory feet. The authors concluded that although success following this operation is not assured, the procedure, nonetheless, has a definite place in the management of refractory talipes equinovarus.

Tuesday, January 27

Treatment of Comminuted Calcaneus Fractures by Primary Triple Arthrodesis. Dr. Kearns R. Thompson [42] and Dr. Carl M. Friesen [43] reported their results in the treatment of twenty-six comminuted, displaced fractures of the calcaneus in twenty-five patients by primary triple arthrodesis.

Conventional roentgenographic evaluation of the fractured calcaneus by anteroposterior views of the ankle, and lateral and axial projections of the calcaneus failed to portray the extent and nature of the fracture. Two additional roentgenographic projections are necessary: an anteroposterior view of the mid-tarsal joint and a lateral-oblique view of the calcaneus. These additional views show the condition of the calcaneocuboid joint.

It is the authors' view that painless function cannot be achieved in the presence of disruption of the posterior articular surface of the calcaneus; comminution, with lateral spreading; and fracture of the cuboid articular surface. An analysis of the twenty-six operations, with a follow-up extending from six months to nine years, revealed that all the patients returned to their former employment in an average of 6.25 months after injury.

Twenty-one patients had excellent results, three had good results, and one patient had a fair result.

Open Reduction and Subastragalar Fusion in Fractures of the Os Calcis. Dr. Homer H. Stryker [44] and Dr. Harold J. Meiers [45].

Epiphyseal Fractures: A Microscopic Study of the Healing Process in Rats. Dr. H. Robert Brashear, Jr. [46] reported experiments in which closed adduction fractures through the distal

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46. University of North Carolina School of Medicine, Chapel Hill, North Carolina

femoral epiphysis (Type I of Aitkin) were manually created in young rats, checked by roentgenograms and then reduced. The animals were sacrificed at intervals from immediately following injury to fifty-two days after fracture. Roentgenograms were again made at the time of sacrifice as were microscopic sections of the distal femur. The fracture line was found to involve the hypertrophic zone of cartilage cells on the lateral or distraction side and the deeper layers of the cartilage cells near the center. On the compression side the fracture line passed into the metaphysis separating a small fragment of metaphyseal bone. Three types of healing of these epiphyseal fractures were encountered, depending upon the particular layer of cartilage cells involved in the injury. If the injury was high in the hypertrophic zone of cells, the healing process involved the removal of the cartilage proximal to the fracture line together with the fibrin debris within the fracture. While this went on, the epiphyseal plate distal to the fracture continued to widen as the result of continued growth. Within three weeks the metaphyseal circulation again reached the cartilage plate and normal anatomy was restored. When the fracture line involved deeper portions of the hypertrophic zone, marked widening of the cartilage plate occurred and a second ossification center within the wide epiphyseal plate developed during healing. If the fracture involved the deepest portions of the plate, that is, the resting zone of cells, a defect developed in the epiphyseal cartilage which, if small, healed by ingrowth of normal cartilage from either side. If the defect was large, growth arrest in that portion of the plate occurred.

Ten-Year Analysis of Intertrochanteric Fractures of the Femur. Dr. Mather Cleveland, Dr. David M. Bosworth [47], Dr. Frederick E. Thompson [48], and Dr. Hudson J. Wilson, Jr.[49] reported a series of 239 consecutive trochanteric fractures of the femur treated at St. Luke's Hospital, New York, N. Y., during the period from January 1947 to January 1957, a sequel to a similar series of 133 fractures reported in January 1947. Whereas one-third of the fractures in the previous series were treated by traction, internal fixation was used in all but ten of the present series. In these ten cases surgical intervention was contra-indicated for one reason or another. A Jewett nail was used for fixation in all, with the exception of one blade plate and one splint. A detailed statistical analysis of this series was reported. Twenty-four of the patients died before discharge, three within seventy-two hours of the operation, and eighty-one were known to be dead at the time of this study. The average stay in the hospital for those operated upon was fifty-three days. The average stay was 100 days for five patients who were treated successfully by traction alone. There were four deep and six superficial wound infections, all of which healed. The average length of follow-up for the patients discharged from the hospital was thirty-three months. There were two non-unions of fractures. Nine nails broke and one bent. The nail penetrated the femoral head in twenty-three instances but had to be removed in only four because of pain. In twelve others the nail cut out of the head and neck. Fourteen patients had more than one operation in order to realign the fragments, to replace broken nails, to graft a delayed union, or to remove the nail. The authors concluded that placement of the nail low and posterior in the head was important, and that loss of fixation was inevitable in some cases.

Recent Advances in the Reconstructive Surgery of Major Arterial Lesions. Dr. Robert R. Linton [50] said that during the past decade, outstanding progress has been made in the treatment of diseases and injuries of the major arteries in man. The most important of these new methods have been the restoration of arterial continuity by various types of vascular grafts and restoration of the arterial lumen in occlusive arterial disease by endarterectomy.

The most common indications for blood-vessel grafts are: (1) obliterative arterial disease, secondary to atherosclerosis obliterans in which it is impossible to restore the arterial lumen by endarterectomy; (2) aneurysms involving the thoracic and abdominal aorta and the major arteries of the limbs, in which after removal of the aneurysm the aortic and arterial continuity can be restored with a graft; (3) arterial injuries, usually caused by missiles, but in some cases following fractures (in which there has been disruption of an artery) and a graft is necessary to restore continuity; (4) malignant disease involving major blood vessels in which resection of these vessels along with the whole of the primary tumor may be possible if arterial continuity is restored by grafts; (5) congenital blood-vessel anomalies such as coarctation of the aorta which can be resected and continuity restored with a graft.

Various types of grafts were utilized including (1) autogenous venous grafts taken from the same individual and used to replace the arterial segment; (2) homologous venous grafts, which were satisfactory; and (3) homologous arterial grafts, which were used most frequently. The homologous arterial grafts were much more successful than the former type

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of homologous graft, but the autogenous venous graft seemed to stand up best, although it is not often available. At the present time, various types of synthetic fabrics are being used. Eventually they may replace human grafts. The most satisfactory ones are made of dacron and teflon. As yet, sufficient time has not elapsed to determine how long these will function, but at the present time, the results seem to be encouraging.

The author believed that there are ten requirements for a successful blood-vessel graft. The first is that accurate arteriograms with good roentgenographic visualization of the diseased arteries should be made in order to determine if it is possible to implant a graft. Second, a satisfactory graft must be available. There must be an adequate inflow of arterial blood to keep the graft functioning, and equally important, there must be an adequate peripheral arterial bed distal to the graft (what is known as a run-off) otherwise the graft will become occluded. Meticulous technique is of great importance in this type of surgery. It would be impossible to carry out these long operations without antibiotics, which are used as prophylaxis against infection. It would also be impossible to carry out this type of surgery without the use of the anticoagulant, heparin, since arterial thrombosis, if it occurs during these operative procedures, will cause failure of the procedure. Multiple blood transfusions must be available for the larger procedures and, for this reason, an adequate blood bank is essential. A shockless type of anaesthesia, so that the patient's blood pressure is maintained throughout, is also extremely important and last, but not least, adequate time and patience are essential. This type of surgery is really a task for a perfectionist.

Medullary Fixation of Forearm Fractures with a Study of the Medulla of the Radius and Report on 50 Patients Treated by a Pre-Bent Nail. Dr. Fred P. Sage[51] studied the shape, size, and contour of the medullary canal of the radii of 100 cadavera. In each instance death had been associated with chronic illness or senility, and accordingly the widths of the medullary canal in these specimens were probably not so small as they would be in normal clinical material. However, the contour and angles of the canal would be anticipated to be the same. The study showed that there are four curves within the cortical boundaries of the radius; two distal curves are located in the anteroposterior and lateral planes and extend from the distal end of the radius proximally to the mid-part of the medullary canal opposite the bicipital tubercle. These two arcs are subtended by an angle whose apex is located at the mid-point of the medullary canal opposite the middle of insertion of the pronator teres on the radius. The radialward angle in the anteroposterior projection averaged 9.3 degrees, whereas the dorsal angle seen in the lateral projection averaged 6.4 degrees. The other two curves form paired proximal angles which blend with one another and are opposite in each direction in each plane to the two distal angles. These two proximal paired angles are responsible for the eccentric location of the radial head and average 13.1 degrees extending from the mid-point of the proximal end of the radius to the middle of insertion of the pronator teres on the radius with the apex of the angle subtending this arc located at the mid-point of the medullary canal opposite the bicipital tubercle.

From this study of the radii of cadavera, a fixation device for the radius was devised which is triangular in cross-section to prevent rotation, and pre-bent to conform to the average contour of the medullary canal of the radius yet is sufficiently springy to bend as it traverses the medullary canal from a point of insertion on the radial styloid process. The proximal end is rounded for a skid and the distal end is threaded to permit the attachment of a driver during insertion. Straight pins, triangular in cross-section and threaded on each end, are used in the ulna.

Among the first fifty patients in whom the nail for the radius was used, either alone in solitary fractures or in both the radius and the ulna in combination, there were eighteen solitary fractures of the radius with union in 94.4 per cent and non-union in 5.6 per cent. In thirty-two fractures involving both bones, the radius united in 93.8 per cent and failed to unite in 6.2 per cent, while in the ulna, union occurred in 93.3 per cent. This group of fractures presented a formidable challenge to medullary fixation for there were numerous preoperative complicating factors.

Several operative complications were encountered. The most persistent difficulty was in driving the nail down a tight medullary canal. By altering the nail and the technique for insertion, these complications now, for the most part, can be circumvented.

The pre-bent triangular nail for the radius is indicated in any diaphyseal fracture exclusive of the proximal fourth and the distal third, provided the medullary canal is not too small. The straight triangular medullary nail, threaded on each end, may be used in the ulna in any diaphyseal fracture when adequate precaution as to canal size is observed.

Barton's Enigma. Dr. Richard E. King[52] and Dr. Wood Lovell[53] discussed the fracture-dislocation of the wrist known as Barton's fracture. This entity was described in 1838 by

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Barton, who also reported several cases. Barton's fracture consists of a fracture involving the articular surface of the radius with the distal fragment carried volarward or dorsalward with the dislocated carpal bones. It may be confused with a Smith fracture.

The cause of the Barton fracture-dislocation is usually a fall in which the impact of the body weight is sustained by either the palm or the dorsum of the hand. Through the medium of the volar or dorsal radiocarpal ligaments, a tremendous wedging and leverage action is exerted on the lower end of the radius. The dislocation appears to be secondary to the fracture of the distal radius and is the result of the continuation and dissipation of the injuring force.

It was initially thought that the disruption of the dorsal or radiocarpal ligaments permitted the dislocation to occur. However, it was shown experimentally that if either the volar or dorsal ligament is intact, the radius must fracture to allow the carpus to dislocate either dorsally or volarward, respectively. In this concept lies the key to the reduction and the maintenance of the reduction.

The stability of the reduction depends upon the intact ligament on the surface of the radiocarpal joint opposite the fracture-dislocation. If the fracture and dislocation are dorsal, the wrist should be immobilized in extension to take advantage of the intact volar carpal ligament. Conversely, if the displacement is volarward, the wrist should be immobilized in flexion to take advantage of the intact dorsal ligament. It is to be emphasized that this fracture is a treacherous one and frequent roentgenographic examinations are necessary to detect displacement after reduction. One should not hesitate to remanipulate several times in order to obtain a good result both anatomically and functionally. The wrist is maintained in the flexed of extended position with plaster splints for approximately ten to fourteen days. An attempt should then be made to bring the wrist into a neutral position and a snug, forearm cast applied. Total immobilization should be for approximately six weeks.

Deformity Following Supracondylar Fractures of the Humerus. Dr. Lyman Smith [54] pointed out that most of the literature concerning supracondylar fractures of the humerus has stressed such complications as ischaemia, nerve paralysis, myositis ossificans, and stiffness whereas, as a matter of fact, these complications are rare compared with the high incidence of changes in the carrying angle of the forearm following this fracture (from 10 to 57 per cent in various series of cases). In this presentation it was shown that both apposition of the fragments and axial rotation of the distal fragment had no appreciable effect on the carrying angle, whereas medial or lateral tilt of the distal fragment did change the carrying angle. Such medial or lateral tilting may be present, yet partially or completely concealed in the roentgenograms. In contrast to this, it was demonstrated that even slight tilting of the distal fragment was obvious in direct observation of the posterior aspect of the flexed elbow.

For these reasons, it was recommended that the completely displaced fractures be treated visually, that is, in skeletal traction with the arm overhead so that the fragment alignment can be under constant observation and positive control. After ten to fourteen days callus was usually considered adequate to stabilize the fragments sufficiently for a cast to be applied. The author had treated twelve cases in this fashion; the cosmetic and functional results had been excellent.

Wednesday, January 28

The Correlation of Arthrograms of the Knee with the Pathology Found at Surgery. Dr. Vernon C. Turner [55] and Dr. Flora Brown Wurtz [56] reported a series of 188 meniscal injuries of the knee in which preoperative arthrograms, using 35 per cent diodrast, were performed and the results of this diagnostic procedure compared with findings at surgical exploration. The diagnosis made by arthrography corresponded to the operative findings in 80 per cent of the injuries to the medial meniscus and in 27 per cent of the injuries to the lateral meniscus. The procedure proved of greatest value in patients with atypical or only suggestive signs and symptoms but was also of benefit in the diagnosis of tears of the posterior one-third of the medial meniscus which could not be visualized through the usual anterior surgical approach.

Translocation of the Peroneus Longus Tendon for Paralysis of the Triceps Surae. Dr. Edward D. Henderson [57], Dr. Joseph M. Janes [58], and Dr. Earl C. Elkins [59] discussed forty-seven operations (forty-two patients) in which the tendon of the peronaeus longus muscle was translocated to the posterior aspect of the calcaneus to provide plantar flexion power, to prevent calcaneus deformity, and to improve the gait in the presence of paralysis of the triceps surae.

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59. 200 First Street, S.W., Rochester, Minnesota

The ages of these forty-two patients ranged from one to twenty-nine years. The paralysis was the result of poliomyelitis in all but two patients; one of the two had a congenital calcaneus deformity and the other had an injury of the tibial nerve. Thirty-six of the patients had been followed for more than three years. The shortest time of follow-up was six months. Calcaneus deformity had developed in thirty-one of the forty-seven extremities prior to operation.

Indications for the operation are: (1) weakness of the triceps surae, sufficient to produce calcaneus deformity or limp and (2) normal or near-normal power in the peroneal-muscle group.

The operation consists in transferring the peronaeus longus tendon from its normal course behind the lateral malleolus beneath an undermined flap of skin to a groove in the postero-inferior aspect of the os calcis. This is done through two curved incisions, the anterior one being the longer. Postoperatively the foot is immobilized in a plaster cast for two to three weeks with the ankle in full plantar flexion; great care is taken to keep the foot in a neutral position to avoid depression of the first metatarsal head. After removal of the cast a period of four to six weeks of physical therapy, including stretching, re-education, and strengthening of the transferred muscle, is carried out.

The results were evaluated only on the basis of arrest or correction of the calcaneus deformity and increased plantar flexion power. Other muscle weakness and deformities were not taken into account. The results were as follows: excellent (plantar flexion strength sufficient to hold the heel off the ground) in twenty (42.5 per cent); good (plantar flexion strength good, but insufficient to hold the heel off the ground) in twenty (42.5 per cent); poor (only calcaneus deformity arrested) in four (8.5 per cent); and failure (no function) in three (6.5 per cent). The difference between an excellent and a good result appeared to depend on the presence of some residual contractile power in the plantar flexor muscles.

Complications included slow wound healing in three patients, breakdown of the skin flap in one patient, postoperative varus deformity of the foot, not present preoperatively, in four patients, and excessive tightness of the translocated peronaeus longus tendon requiring lengthening in order to get the heel to the floor in four patients.

This operation has the following advantages over transplantation of the tendon: (1) the tendon is transferred without disturbing its continuity, (2) the tendon is transferred without the necessity of suture, (3) the period of immobilization is shorter, and (4) the tendon is placed under tension immediately, so that loss of strength and tone is prevented.

Osteocartilaginous Grafts in Dogs. Dr. David N. Hawkins[60] and Dr. Rocco A. Calandruccio[61] created osteocartilaginous defects in the femoral condyles of dogs and studied the fate of these defects when these were left alone and when these were filled with autogenous and frozen homogenous osteocartilaginous grafts. If no graft was used, the defect persisted as a depressed fibrocartilaginous scar on the articular surface with some evidence of degeneration of the surrounding hyaline cartilage. In the first autogenous grafts both bone and cartilage survived, whereas in the homogenous transplants the bone and cartilage died, the bone being gradually replaced by creeping substitution and the cartilage by fibrous tissue and poorly developed fibrocartilage. On the basis of these experiments, suggestions were made as to the treatment of osteochondritis dissecans.

An Evaluation of the Use of the Short Stem (Judet Type) Prosthesis in Reconstructive Surgery of the Hip. Dr. Philip D. Wilson, Jr.[62] and Dr. Joseph B. Mason[63] reviewed the results of 105 of 143 prosthetic arthroplasties of the hip, evaluated after a follow-up period of no less than two years. (Average follow-up was between four and five years.) Vitallium inserts were used in sixty-nine and acrylic prostheses in thirty-six of the patients. The clinical results were considered satisfactory in eighty-three and unsatisfactory in twenty-two of the patients.

Follow-up roentgenograms were available in ninety cases. These revealed loosening of the prosthesis with actual instability in twenty-three hips, as well as cystic degeneration of the acetabular roof. With the Vitallium prostheses, this degeneration seemed to be the result of insufficient revision of the osteo-arthritic acetabulum at the time of operation. However, degeneration was most marked in some of the hips with acrylic prostheses where wear of the prosthetic surface had been suspected. Cystic degeneration of the acetabulum seemed to be the most significant factor in explaining pain in several of the failures.

The results are analyzed according to the various diagnostic groups—osteo-arthritis, rheumatoid arthritis, aseptic necrosis, and non-union. The following conclusions were made:

1. Although absolute fixation of the Vitallium head-straight-stem prosthesis in bone is seldom if ever achieved, a stable relationship had been maintained (at least for the length of the study) in 75 per cent of our cases.

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2. Accurate emplacement of the prosthesis is important for stable fixation and good results.

3. While the results of this operation cannot be predicted accurately, we feel that they have been sufficiently satisfactory to justify continued use of the prosthesis when indicated, until such time as a better method is devised.

4. One of the major criticisms of endoprostheses in general has been that potentially valuable bone stock is sacrificed unnecessarily. With the type of prosthesis under discussion, little more than diseased bone is usually removed. Once inserted, a head-straight-stem prosthesis most nearly re-establishes the mechanical relationships in the hip which are desirable for satisfactory function of the hip.

Acetabular Stress Resulting from Incongruence of Femoral Head Prostheses. Dr. Philip H. Davis[64] and Dr. Mihran Tachdjian[65] reviewed forty subcapital fractures of the femoral neck which had been treated by the insertion of a metallic prosthesis and found that more or less acetabular migration occurred unless the prosthesis fitted the acetabulum to within a tolerance of one-thirty-second of an inch. In a mechanical analysis of the hip joint, the authors stated that theoretically a metallic head smaller than the acetabulum will reduce the weight-bearing area to a contact point without any area. On the basis of studies of cartilage compression the authors calculated the pressure on the weight-bearing area of the acetabulum of a 175-pound man, assuming the acetabulum to be two inches in diameter. With a perfectly fitting femoral head the pressure was calculated to be 150 pounds per square inch. With a metallic prosthesis the pressure ranged from 300 pounds per square inch if the diameter of the head was one-thirty-second of an inch less than that of the acetabulum, up to 1,000 pounds per square inches if the diameter of the head was one-eighth of an inch less than that of the acetabulum. The author concluded that if the metallic head is smaller than the acetabulum, the increased contact pressure may cause necrosis of the cartilage and subchondral bone with resultant acetabular erosion. Since the Austin Moore prosthesis comes in size increments of one-eighth of an inch, it is impossible in a certain number of hips to obtain a fit much closer than one-eighth of an inch. The problem of acetabular erosion would appear to resolve itself into one of securing a perfect or close-to-perfect fit of the metallic prosthesis in the acetabulum.

Kappa Delta Award Paper

Molecular Structure and Biological Specificity in Mineralization. Dr. Melvin J. Glimcher[66] first reviewed briefly those general aspects of crystal nucleation, formation, and structure which form the background of his studies. He discussed the elementary characteristics of equilibria and the kinetics of the phase change which occurs when crystals are formed in a solution. In particular, he discussed the problem of heterogenous nucleation in a solution in metastable equilibrium as it might apply to collagen in solutions of calcium and phosphate ions. He then described his experiments with *in vitro* preparations of collagens in seven different states of aggregation. These preparations, when exposed to various calcium phosphate solutions, did not show nucleation of apatite except when the collagen was in the "native state" and the solution was supersaturated with regard to calcium phosphate. The specificity for nucleation of mineral crystals was discussed in terms of the chemical ions or ion groups involved, and the crystal lattice structure. The fact that untreated, fresh collagen fibers did not nucleate the crystals, while after extraction they did, led him into a discussion of what mechanisms might exist to inhibit calcification in collagen *in vivo* and what might allow it to proceed.

In a second, shorter portion of his paper, the author discussed his electron-microscopic and roentgenographic diffraction studies of bone and of *in vitro* calcified collagen. He reviewed the geometry, which is pertinent to these studies, and presented observations to confirm recent suggestions that crystals first form (nucleate) within the fibers, without orientation of the C-axis parallel to the fiber. He then postulated that crystal growth can result in orientation of the C-axis parallel to the fiber.

Results of Treatment of Congenital Dislocation of the Hip. Dr. Ignacio V. Ponseti[67] and Dr. Edgar Frigerio[68] reviewed the anatomical results in congenital dislocations of the hip of patients who were treated when they were under four years of age during the period 1942 to 1950, and in preluxations treated from 1942 to 1954. The study included thirty-nine preluxations with a minimal follow-up of four years; eleven subluxations and seventy-four dislocations with a minimal follow-up of eight years. The dislocations were reduced with the child under general anaesthesia; only three open reductions were done when closed reduction failed. Rotation osteotomy was done in thirteen instances.

64. 376 College Street, Burlington, Vermont
65. Fort Knox, Kentucky
66. Massachusetts General Hospital, Boston 14, Massachusetts
67. University of Iowa, Iowa City, Iowa
68. University of Iowa, Iowa City, Iowa

Good anatomical results were obtained in all preluxations and subluxations and in fifty-two of the dislocated hips. The anatomical results were unsatisfactory in the remaining twenty-two dislocated hips of which eleven had hip dysplasia; five, moderate subluxation; and six, severe subluxation. No redislocations occurred.

The importance of early treatment was emphasized by this study. Good anatomical results were obtained in all cases initially treated before the patient was one year old, and in 78 per cent of the cases treated when the child was one to two years of age. In contrast to this, good anatomical results were obtained in only 57 per cent of the cases who were treated when the child was two to four years of age. The orthopaedic surgeon must collaborate with the pediatrician to disclose all cases of congenital dislocation of the hip in early infancy. Ortolani's snapping sign is the only unequivocal sign of early dislocation.

The Pathogenesis, Significance, and Treatment of Subchondral Cysts of the Iliac Acetabulum. Dr. G. W. N. Eggers [69], Dr. E. Burke Evans [70], Mr. James K. Butler [71], and Dr. Johanna Blumel [72] observed that the development of cysts in the acetabulum may accompany, and even precede, obvious arthritic changes in the hip. A survey of 350 roentgenograms of the pelves of people under twenty did not disclose a single instance of the condition, whereas in routine examinations of patients in the twenty to forty-year group several lesions were discovered. After the age of forty years, both unilateral and bilateral cysts were found more frequently. In most cases, the condition does not cause symptoms until the wall of the cavity becomes sclerosed, or fracture and collapse of the cavity ensue at which time pain usually develops.

In the early stages, when there is only discomfort and little pain, the authors found that ablation of a cyst by filling it with chip grafts often completely relieves symptoms, the success of the procedure depending upon the severity of the involvement. The more extensive lesions require arthroplasty using either a cup or prosthetic appliance but the success of these procedures, in the authors' experience, depends upon soundness of the acetabular cavity. If cysts are not obliterated, the hip remains painful.

The cysts, although varying in roentgenographic appearance, have a consistent anatomical location under the antero-inferior iliac spine at or near the junction of the acetabular cartilage with the labrum acetabulare. This is the point where the pressure of weight-bearing is greatest and most consistent. The cysts may thus represent a response to the degenerative changes in the cartilage at this point, a response which is characterized by fibroblastic proliferation and the eventual appearance of cartilage and osteoid elements in the immediate subchondral area. These cavities at first contain fibrous tissue and other mesodermal structures. As the surrounding bone becomes sclerotic, the vascular supply is decreased and the fibrous tissue may degenerate centrally, leaving a cavity which may or may not be filled with fluid. At some point during the process of cyst formation a connection develops between the cyst and the joint cavity. This has been demonstrated clinically in several instances.

Experimentally, it has been observed that after prolonged immobilization of the knee joints of a rat, cysts of the femoral condyle may develop, which are strikingly similar to those seen clinically in the acetabulum. The pathogenic sequence observed in the femur of the rat seems to support the authors' concept of pathogenesis of acetabular cysts.

In the authors' opinion, the successful treatment of these cysts by ablation and grafting depends upon the interruption of the destructive sequence and the restoration of acetabular integrity. Early recognition and definitive surgical treatment of the condition will prevent or forestall invalidism caused by the hip, will often restore good hip function, and will assure more satisfactory results in certain cases in which the patients require prosthetic or cup arthroplasty.

Thursday, January 29

A Clinical Study of Demineralizing Bone Disease. Dr. James A. Nicholas [73], Dr. Philip D. Wilson [74], and Dr. Robert Freiberger [75] presented a study made of 162 patients admitted to the Hospital for Special Surgery since 1950 because of vertebral compression fractures with associated demineralization. The data on 105 of these patients made up the material for this report. The data on the remaining fifty-seven patients were discarded because of known diagnosis at the time of admission, adequate trauma for vertebral compression, or inadequate work-up.

Among the 105 patients, twenty-seven were under fifty-five years of age. Of these, eleven had malignant conditions, five had osteoporosis, and the other eleven had a variety of causes

69. 2201 Avenue "D", Galveston, Texas
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71. University of Texas Medical Branch, Galveston, Texas
72. University of Texas Medical Branch, Galveston, Texas
73. 110 East 87th Street, New York 28, N. Y.
74. 535 East 70th Street, New York 21, N. Y.
75. Hospital for Special Surgery, Cornell University Medical College, New York, N. Y.

for their demineralization. Of these seventy-eight patients over fifty-five years of age, fourteen had malignant conditions; fifty, osteoporosis; while the remaining fourteen patients had other conditions.

Six patients were found to have demineralization associated with myasthenia gravis, polycythaemia vera, Waldenström's macroglobulinaemia, malignant lymphoma, Milkman's disease, and ankylosing spondylitis. One-third of the patients had histories of significant gastro-intestinal disease and no milk intake. Menopause occurring under the age of forty was noted in eight patients. Severe demineralization was present in the patients with rheumatoid arthritis treated with corticosteroids.

Direct biopsy established the diagnosis in ten of twenty-five patients and a marrow examination in thirteen of forty-eight patients was positive. Several patients required as many as three or four marrow examinations before a final positive diagnosis was established.

It was evident that the chance of malignancy as a cause of the demineralizing process was markedly increased if the patient was under fifty-five and had less than three compression fractures. Increased numbers of compression fractures were apt to be associated with diseases other than malignancy, except myeloma.

Osteomalacia was found in six of 105 patients. It was felt that this disease was less rare than has been reported by a number of American authors. It may be that it is associated with decreased calcium intake or disease of the gastro-intestinal tract, both of which were frequent in this series.

A Survey of Low-Back Facet Bone-Block Fusion Operations. Dr. Elias Margo[76] and Dr. Marvin K. Margo[77] presented the results on 1,264 operations performed at the McBride Clinic and Bone and Joint Hospital during the period from 1948 through 1957 for lesions of the intervertebral disc, traumatic affections, congenital instability, spondylolisthesis, and spondylolysis. Of these, 1,160 had facet bone-block fusions with complete follow-up data available on 1,065 of these including both clinical examination and biplane-bending roentgenograms one or more years after surgery. The operative technique and postoperative management were described. The clinical results were classified on the basis of pain and the patient's ability to return to his original occupation. With these criteria the results in 88 per cent were classified as good; 7 per cent, fair; and 5 per cent, poor. Solid fusion was obtained in 81 per cent, fusion at the lumbosacral interspace but not at the interspace above in 15 per cent, and complete failure of fusion in 4 per cent. Among the 104 patients in whom fusions were not performed (seventy-nine simple disc excisions and twenty-five Gill procedures for spondylolisthesis) the clinical results were good in ninety-five, fair in six, and poor in three. There were fifteen postoperative infections, thirteen of which extended into the interbody region. Six deaths occurred within forty-three days of the operation, but only two of these were related to the surgery. A variety of second operations for one reason or another were required in forty-five patients. The authors concluded that facet bone-block fusions using the spinous processes for the grafts are practical and efficient, that locking the grafts in place by spreading the interspace is essential, and that lumbar fasciotomy at the time of fusion is desirable.

Discography—Usefulness in Clarification of Clinical Syndromes. Dr. Norman M. Harris[78] and Dr. Anthony J. Smith[79] discussed the value of discography in the diagnosis of clinical syndromes having an etiological basis in intervertebral-disc pathology, emphasizing that this procedure permits visualization of the internal structure of the disc, and helps to distinguish symptomatic abnormal discs from asymptomatic discs by reproducing symptoms caused by the former. Discography is considered superior to both myelography and surgical exploration, since it identifies non-protruded degenerated disc and demonstrates posterolateral and anterior protrusion or herniation outside the limits of the vertebral canal.

The lumbar discogram has been found to be of particular value in identifying the cause of common, incapacitating low-back pain since, in the authors' opinion, it can be shown that these symptoms are associated with disc degeneration and presumably arise from abnormal motion at the involved level with resultant ligamentous irritation.

The discogram of the cervical spine was found to be particularly useful. Irritation of the cervical spinal cord and nerve roots, the vertebral arteries, the autonomic pathways, and the ligaments of the cervical articulations can give rise to remote, and occasionally, bizarre symptom patterns, the origin of which are difficult to localize. When the discogram has reproduced the presenting symptoms, the roentgenogram has always shown a degenerated or herniated disc. It is the authors' belief that change in the disc is the underlying abnormality which causes symptoms in patients with so-called whiplash injuries, cervical arthritis, and similar conditions. This belief has been strengthened by the fact that relief of symptoms, reproduced

76. McBride Clinic, 605 N.W. 10th Street, Oklahoma City, Oklahoma
77. McBride Clinic, 605 N.W. 10th Street, Oklahoma City, Oklahoma
78. 320 West Central, Coos Bay, Oregon
79. Coos Bay, Oregon

by discography, has been obtained by successful interbody fusion of the symptomatic interspace. The discogram has thus made possible definitive anatomicopathological diagnoses, and has opened the way for rational and effective therapy.

The Role of the Surgeon in Disaster Management. Dr. Joseph R. Shaeffer [80] said that the medical problems during any disaster concern the rescue and treatment of the injured. Local medical resources must be immediately mobilized to render emergency care to the injured survivors, which may be life-saving for some but necessary for restoration of sound health for all.

Disasters occur as freaks of nature, as the result of man's ignorance and carelessness, and as the result of man's constant conflict with man.

Trauma today grows in significance and is a major concern of all. The discovery and capture of the tremendous power contained within the atom and its conversion to instruments of war has produced atomic devices which can devastate vast areas with the speed of light. Time and distance as protective barriers have shriveled. Metropolitan and industrial areas are strategic targets.

The care of the injured in any disaster is a medical responsibility. The principles of traumatic surgery have been well documented and are still under continuing study. However, interest in trauma as a distinct branch of medical science seems to have been downgraded in our training programs in preference for the more exotic fields of specialization.

For national defense, organized medicine and, indeed, every physician must be a part of the team. There is much to be done. The principles for the medical management of a nuclear disaster must be defined and promulgated. The lay public must receive appropriate instruction and training in self-care. Casualty care must have a more prominent place in our formal training programs and professional meetings. The importance of modifying treatment to meet the requirements of the large numbers of casualties which inevitably follow a major disaster must be appreciated and accepted before the catastrophe occurs if the medical profession is to execute its mission properly. When excessive numbers of casualties occur simultaneously, priority for treatment is essential.

Anterior Lumbar Intervertebral-Disc Herniation. Dr. Henry L. Feffer [81] and Dr. John P. Adams [82] reviewed the existing knowledge of the intervertebral disc in health and disease, with particular reference to the anterior aspect of the disc. The densely innervated, fibrous, anterior longitudinal ligament, with its firm bone attachment and loose connection to the disc, is thought to be poorly adaptable to pressure changes from within the interspace. In contrast, the less sensitive, elastic, posterior ligament would appear to be free to separate relatively easily from its vertebral attachments, thus accommodating a protrusion from within.

Anterior herniation of a lumbar intervertebral disc is not uncommon and presents a clinical picture of a gradual, atraumatic onset of diffuse low-back pain radiating to the lower abdomen, groin, and thighs. A reversed lumbar curve, with or without lateral deviation of the spine, usually is accompanied by unrestricted straight-leg raising. A simultaneous posterior protrusion at the same or another level, however, often can confuse the picture. Routine roentgenograms, made late in the development of this process, reveal marginal osteophytic formation, but the diagnosis may be confirmed by a discogram.

The Role of Anterior Interbody Cervical Fusion in Traumatic Fracture Dislocations and "Spontaneous" Dislocations Following Previous Cervical Laminectomy. Dr. Robert W. Bailey [83] and Dr. Carl E. Badgley [84].

Symposium on the Role of Metallic Implants in the Treatment of Fractures. Dr. Albert B. Ferguson, Jr. [2], Dr. Carl D. Martz [85], Dr. Charles O. Bechtol [86], Mr. Patrick G. Laing [1], Dr. Jonathan Cohen [87], and Dr. Jack K. Wickstrom [30], *Moderator*. This timely and important instructional course was conducted by the members of the Committee on Biomechanics and Implants.

An introduction and historical summary of the use of metals in bone surgery were given by Dr. Jack Wickstrom. Dr. A. B. Ferguson, Jr., followed with a summary of the main features of corrosion as it occurs in metals which have been implanted into the body. This presentation emphasized the theoretical aspects and reactions which may occur when a metal

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84. 1405 East Ann Street, Ann Arbor, Michigan
85. 23 East Ohio Street, Indianapolis 4, Indiana
86. University of California Medical Center, Los Angeles 24, California
87. 300 Longwood Avenue, Boston 15, Massachusetts
88. 384 Post Street, San Francisco, California

corrodes and included a discussion of metallic transfer. Mr. P. G. Laing next described the metallurgical characteristics of the various metals now being used in the manufacture of metallic appliances. He emphasized the differences in chemical composition and in techniques of manufacture in regard to the products obtained. Dr. Jonathan Cohen followed this presentation on metallurgy with an account of the various ways in which metallic implants have been shown to fail and summarized methods which can be used to investigate these failures and prevent their occurrence in the future. Dr. Charles Bechtol followed with a discussion of some of the factors in the design of apparatus which determine the mechanical effectiveness of internal fixation. The different characteristics of screws and the effect of these differences on the holding power of screws were part of the discussion. Dr. Carl D. Martz next presented the manufacturers' problems of production and control of the specifications of appliances in general. The course concluded with a presentation by Dr. Floyd H. Jergesen [*] of the common technical errors of application of metallic devices and their relation to clinical and material failure.

THE ORTHOPAEDIC RESEARCH SOCIETY

The Fifth Annual Meeting of The Orthopaedic Research Society was held in Chicago, Illinois, January 23 and 24, 1959. The officers of the Society for 1959 are as follows:

President: Robert D. Ray;
President-Elect: Ignacio V. Ponseti;
Secretary-Treasurer: Paul H. Curtiss, Jr.

The Orthopaedic Research Society welcomes all who may be interested in applying for membership. The requirements for membership are primarily a present and continuing interest in research related to the field of orthopaedic surgery. The Society is particularly desirous of receiving applications from younger investigators as well as from Canadian and other orthopaedic surgeons who feel that they will be able to meet the responsibilities of continuing membership. At the present time, membership is automatically forfeited by an active member if he fails to attend three consecutive meetings without suitable excuse and, if for five consecutive years, fails to submit to the Program Committee a subject for presentation.

Applications for membership should be sent to the Secretary, Dr. Paul H. Curtiss, Jr., 2065 Adelbert Road, Cleveland 6, Ohio.

The following new members were elected:

John P. Adams
Kirk J. Anderson
H. Robert Brashear
Felix Bronner
Lee J. Cordrey
William R. Duncan
Robert B. Duthie
F. Gaynor Evans*
J. George Furey
David S. Grice
William R. Harris
Patrick J. Kelly
Robert K. Lippman*
Henry O. Marsh
Julius S. Neviaser*
George E. Spencer, Jr.
Wayne O. Southwick
Richard Kerr White

The next meeting of The Orthopaedic Research Society will be held immediately preceding the 1960 Annual Meeting of The American Academy of Orthopaedic Surgeons in Chicago, Illinois.

Application forms for submission of abstracts for presentation at the next meeting may be obtained from the Secretary. However, no abstract received after October 1, 1959, can be considered for the 1960 Meeting. One need not be a member to submit an abstract.

Abstracts of the papers presented at the Scientific Sessions are as follows:

Observations on the Molecular Biology of Rickets. Dr. Huntington Sheldon [1], Dr. Robert A. Robinson, and Dr. Roland F. Beers stated that the increasing interest in disease of connective tissue emphasizes gaps in our knowledge of the components of various connective tissues. For this reason they undertook a study of a specialized connective tissue (bone) in a situation where variables could be experimentally controlled (rickets in rats on a vitamin-D-deficient, low-phosphate diet). Light and electron-microscope, tissue-culture, and biochemical observations on the relationship between cells of bone and elaboration of bone matrix under normal and experimentally altered conditions in an effort to elucidate the possible origins of soluble and fibrillar collagen were reported. In addition, they hoped to shed light on the

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structural relationship between collagen and hydroxyapatite during early stages of calcification in healing rickets.

Sections from bone adjacent to the epiphyseal plate of rats on normal and rachitogenic diets before and after correction of the low-phosphate state by varying doses of inorganic phosphate or adenosine-monophosphate were studied with light and electron microscopy and in tissue culture. Organic and inorganic phosphate determinations on serum and various representative tissue were made. On the low-phosphate diet, lesions of other organs in addition to well known lesions of bone were observed; these disappeared following the administration of phosphate. Specific changes in bone cells precede the calcification of osteoid and the healing of rickets. Observations to support the hypotheses (1) that collagen is elaborated by the cell in non-fibrillar form and is seen in a particular component of the cell cytoplasm, and (2) that under certain circumstances this non-fibrillar collagen may be seeded by phosphate while it is within the cell were presented.

Preliminary Observations on the Development of Frozen-Dried Membrane Bone with the Electron Microscope. Dr. Zelma Molnar [2] stated that the parietal bone of one-week-old mice is favorable for the detailed study of the development of membrane bone. Because it is thin, it can be stained supravitally and observed *in toto* with the light microscope, which is important for orientation purposes. For the same reason it can be satisfactorily fixed by freezing and drying without ice-crystal formation, and the various stages of development may be observed within a single ultra-thin section with the electron microscope. Osteocytes completely fill their lacunae, and there is no significant space between them and the bone matrix.

Several stages of the process of calcification may be observed. In the periosteum, the ground substance is vacuolated, the vacuoles being of the order of 600-900 Å. Electron-dense amorphous bone salts appear somewhat deeper in and around the collagen fibrils. Later, small dense rodlets (20-30 Å × 50 Å) appear within the collagen fibrils. They are aligned parallel to the long axis of the fibrils and form dense and less dense bands within major periodicity of 510-550 Å. Each dense and less dense subband is further resolved into smaller bands, of which there may be as many as nine. In a still later stage, the less dense regions of the bands are filled up with crystals of bone mineral, so that the periodicity is obscured. At the same time the crystals are aggregated to form longer chains or rods (35-60 Å × 125-500 Å) within which the original small crystals may be observed, and crystals appear between the collagen fibrils.

The Effects of Aging on the Mucopolysaccharide Content of the Periosteum as Revealed by Histochemistry and Autoradiography. Dr. E. A. Tonna [3] stated that a study was made, through injections of radioactive SO_4^{35} and histochemical techniques, in order to ascertain the effects of aging on the localization and distribution of mucopolysaccharides in the femoral periosteum and adjacent bone of rats ranging from newborn to aged. Autoradiographs indicated that SO_4^{35} became predominantly localized at the vicinity of the pre-osseous zone and adjacent osteoblasts. The activity was greatest in the youngest group, and diminished sharply, levelling off around twenty-six weeks of age. Histochemical reactions revealed the presence of metachromasia at the pre-osseous zone throughout the life of the animal, whereas active osteoblasts were mostly orthochromatic. When osteoblasts became older and spindle shaped, they exhibited β-metachromasia. Other reactions indicated an increased intracellular and extracellular mucopolysaccharide activity of the osteogenic cells, especially the osteoblasts, up to five weeks of age. This activity was followed by a sharp drop to a low level, which was maintained throughout the life of the animal.

SO_4^{35} activity and γ-metachromasia showed the presence of acid mucopolysaccharides, of which chondroitin sulphate was predominant, in the pre-osseous zone. This indicates that it is perhaps a "local factor" involved in initiating calcification. The lack of metachromasia in osteoblasts can be taken to mean that chondroitin sulphate is liberated as fast as it is being produced. Other reactions point to the presence of non-sulphate mucopolysaccharides in the osteoblasts, especially during the periods of active bone formation.

Histology of Aging Lumbar Connective Tissue. Dr. Edgar M. Bick [4] stated that a collection of specimens of living human fascia lata from childhood through old age has been studied histologically to observe the changes in collagen fibers, elastic fibers, and periodic-acid reactions. These tissue changes govern the response of connective tissue to trauma and disease of the locomotor apparatus but their life cycle has not as yet been studied.

The Effect of Low and High Calcium Intake on 24-Hour Urinary Calcium Excretion in Patients with Demineralization. Dr. James A. Nicholas [5] and Dr. Philip D. Wilson reported that total urinary calcium excretion had been studied in forty-two patients as part of a comprehensive study of patients who had demineralization with compression fractures. The calcium

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3. Hospital for Special Surgery, New York, N. Y.
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excretion was studied when these patients were on diets of one gram a day as well as of 250 milligrams a day. The effect of restricting the calcium intake was noted. It was evident that the percentage of calcium excreted in the urine rises on dietary restriction when related to the dietary intake. The only significant abnormalities were found in metastatic malignant conditions of bone.

Trace Metals in Normal Rabbit Muscle and Around Metal Implants. Mr. P. G. Laing[6], Dr. A. B. Ferguson, Jr., and Dr. E. Hodge presented the results of careful spectrochemical analysis of samples of normal rabbit striated muscle and also of muscle adjacent to various metal implants. Normal values for this method of iron, nickel, chromium, cobalt, molybdenum, tungsten, titanium, and zirconium were presented. It was demonstrated that the constituent elements of all types of implanted alloys and pure elements can be demonstrated in high concentration in adjacent tissue. Some preliminary deductions of metal corrosion were drawn from the results.

Studies on Some Physical Properties of Radioactive Bone. Dr. F. Gaynor Evans[7] and Dr. David Taysum stated that specimens of a standardized size and shape were machined from the tibial compacta of normal, aging, control, beagle dogs and from those given high-level doses of radium and plutonium. The ultimate tensile strength of the specimens was determined in a Baldwin testing machine equipped with a 600-pound-range air cell so the load could be read to 0.5 pound. The accuracy of the machine was ± 1 per cent. The tensile strain (in microinches) was measured with an SR4 strain gauge extensometer. The modulus of elasticity, stress-strain curves, and energy-absorbing capacity of the specimens were also determined. The age of the dog at death, the burden time, and the cumulative dose were known for the "hot" bones. The relationship of these factors to the results of the tests thus far made was illustrated and discussed. As far as is known, these are the first accurate determinations of some of the physical properties of irradiated bone.

Structural Changes in Dog Skeleton Containing Plutonium. Dr. Webster S. S. Jee[8] and Dr. James S. Arnold observed bone changes in thirty young adult beagle dogs containing body burdens of 2.5, 0.81, and 0.27 microcuries per kilogram of plutonium-239, a bone-seeking alpha emitter, by means of celloidin, roentgenographic, microradiographic, and autoradiographic techniques. The impairment of vascular supply was also studied by India-ink injection of the hind limb at autopsy. The sequence in the development of bone changes was studied in thirteen serially sacrificed dogs containing 2.5 microcurie per kilogram of plutonium; chronic bone changes were studied in seventeen dogs containing 2.5, 0.81, and 0.27 microcuries per kilogram of plutonium and sacrificed with bone tumors (some survived as long as five years after injection).

The early bone changes occurred in trabecular bone, whereas the late changes (except for the bone tumors) occurred in cortical bone. The plutonium was deposited initially on bone surfaces, destroying osteocytes and endosteal and neighboring bone-marrow cells. This resulted in the formation of acellular marrow cavities, peritrabecular fibroses, trabecular resorption, endosteal surface fibroses, or endosteal bone growth. A continuous effect was the disturbance in bone remodelling, producing an excessive number and irregular-shaped resorption cavities, irregular-shaped, hypercalcified and hypocalcified Haversian systems, and eroded periosteal surfaces with fibroses or fractures. The late effect was the induction of osteogenic sarcoma.

The principal trabecular bone changes occurred within 210 days, whereas the first changes in cortical bone occurred at 400 days (plugging of Haversian canals). Plugging of Haversian canals resulted in the death of osteocytes followed by formation of hypercalcified and hypocalcified Haversian systems. These abnormally calcified Haversian systems were found to be the result of the indirect effect of plutonium.

The translocation of plutonium as a function of bone remodelling, the correlation of sites of bone change and plutonium distribution, the location and characteristics of osteogenic sarcoma, and the comparative toxicity of various dosage levels were discussed.

The Vascular Response to Fracture. Dr. James B. Wray[9] and Dr. Clifford J. Lynch said that the existence of a hyperaemia after fracture has been assumed for years. However, a method permitting quantitative evaluation has not been available until recently. They injected the hind limbs of rats with a plastic solution and at stated intervals, after a closed fracture of one tibia. After the plastic hardened, both hind limbs were disarticulated at the hip and chemically digested. At the completion of chemical digestion a mold of the vascular system, including capillaries, remained. The weight of the cast from the fractured limb was compared

6. Children's Hospital, Pittsburgh, Pennsylvania.
7. Wayne State University, College of Medicine, Detroit, Michigan.
8. University of Utah, Salt Lake City, Utah.
9. Bowman Gray School of Medicine, Winston-Salem, North Carolina.

with the opposite normal member. Groups of sixteen or more rats were evaluated at three, six, nine, twelve, fifteen, eighteen, twenty-seven, and thirty-six days after fracture. A statistically significant increase in vascular-bed volume was found to occur at nine days after fracture and to gradually recede to control levels with fracture union. It seems likely that this vascular hyperplasia is vital to fracture healing and that a practical correlation can be developed to permit evaluation of fracture union by the determination of local vascular volume in the living subject.

Comparative Study of Preserved Free Tendon Grafts. Dr. Lee J. Cordrey [10], Dr. Hugh McCorkle, and Dr. Emett Hilton reported that Achilles tendons of rabbits were lyophilized, and preserved in merthiolate and in ethyl alcohol. These free grafts were then inserted into defects created surgically in the Achilles tendons of rabbits. The animals were sacrificed at intervals to compare (1) the degree of healing of the respective grafts, (2) the comparative degree of reaction, and (3) the comparative degree of "revascularization" of the grafts. The individual series of grafts were compared with a group of unpreserved free tendon grafts removed and resutured under similar circumstances.

Production of Congenital Defects in Chickens. Dr. Udaya N. Dash [11] was interested in finding the probable causes of congenital skeletal deformities seen in human beings, and thus insulin, adrenocortical extracts, and nicotinamide were injected in varying doses into the yolk sac of hens' eggs seventy-two hours after incubation. The effects on developed chicks were studied.

Insulin induced various abnormalities of the feet, legs, spine, and back. Adrenocortical extract caused generalized retardation of growth but there were fewer deformities. However, when injected simultaneously with insulin, adrenocortical extract caused an increase of insulin-induced abnormalities. Nicotinamide alone did not induce any deformities. In combination with insulin, it substantially reduced the incidence of insulin-induced abnormalities, but it did not protect against the growth-retarding action of adrenocortical extract. Both insulin and adrenocortical extracts greatly reduced the viability and hatching rate of chick embryos; nicotinamide did not protect against this.

The Alterations in Growth Cartilage in Experimental Dwarfism. Dr. Carl E. Anderson [12], Dr. Jackson T. Crane, and Dr. Harold Harper investigated dwarfed and deformed chick embryos that were obtained by yolk-sac injection of insulin, thallium, and other physiologically effective agents. The femoral and tibial cartilaginous bodies of such dwarfed embryos were studied histologically, histochemically, by tissue biochemistry, and by S^{35} uptake techniques. There appeared to be remarkably little physiological variation from normal, with the exception of the quantity of matrix produced by the chondrocytes in affected areas. The enzymatic steps in the synthesis of chondroitin sulphate were discussed.

The Deforming Effect of Tonic Reflexes of the Foot. Dr. William R. Duncan [13], during the course of a study of the distribution of contractures in cerebral palsy, investigated the possibility that these typical patterns of deformity are caused by repeated stimulation of abnormal or unsuppressed reflexes. The results of these studies suggest that the abundant reflex activity in the foetus and new-born child, if not integrated or suppressed in an orderly manner by an adequate upper neuron system, may contribute to deformity in the normal as well as the palsied child. Four separate tonic reflex movements were elicited in the normal new-born child by appropriate stimulation of four discrete areas on the surface of the foot. These reflexes gradually become unobtainable in an orderly sequence during the first years of life, and it would appear that their timely disappearance is due to a suppressive effect exerted by the maturing central nervous system. If suppression is delayed or disorderly, allowing an abnormal persistence of a single reflex, random environmental stimuli are sufficient to cause the foot to habitually assume the attitude of the reflex movement. Fixation of the foot in this reflex-induced position may eventually occur. In the normal infant such reflex imbalance appears to account for the several transient foot deformities that occur during the first year of life. Fortunately, these deformities tend to disappear with or without treatment during the subsequent years when all such reflex activity is eventually suppressed. In the brain-damaged child, with impaired suppressive ability, these reflex imbalances may persist for years and lead to serious fixed deformity. Thus, a general understanding of tonic reflex activity becomes pertinent to the orthopaedic evaluation and management of certain foot deformities. A knowledge of the normal sequence of suppression offers a further basis for evaluating the maturity (suppressive ability) of the central nervous system. Observations were presented concerning the nature of these reflexes, the adequate stimulus, the normal sequence of suppression, associated muscle activity, and the reflex arc.

10. 4801 Woodmere Road, Tampa, Florida.
11. 4438 West Pine, St. Louis 8, Missouri.
12. 1150 Montgomery Drive, Santa Rosa, California.
13. 1607 Medical Dental Building, Seattle, Washington.

Preliminary Studies in Growth Mechanism in Transplanted Bone. Dr. J. T. H. Johnson [14] and Dr. W. O. Southwick stated that a long-term review of spine fusions at the Johns Hopkins Hospital and Children's Hospital in Baltimore and recent reports in the literature, reveal the fact that spine fusion masses increase in length without an epiphyseal plate.

In an attempt to investigate this elongation mechanism, the authors fused the spines of puppies and young rabbits using autogenous rib grafts. It was found that pseudarthroses formed opposite the disc spaces. This was probably due to an inability to maintain the animals in complete immobilization.

In order to eliminate motion as a factor in the formation of pseudarthroses, intramedullary autogenous grafts of the fibular shafts were placed across the epiphyseal plates of the distal femora of young rabbits. The results in over 100 operations have been studied grossly and by histological serial sections. The following are the most noteworthy types of reactions seen thus far:

1. Epiphyseal-growth suppression by a well fused and solid graft;
2. Loss of continuity of the graft at the level of the epiphyseal line, with little evidence of epiphyseal suppression;
3. Loss of continuity of the graft in the metaphyseal area;
4. Straight-line fibers spanning the bone defect and intense and apparently oriented cellular activity.

An explanation of the elongation mechanism in bone grafts under the stretch of an epiphysis may be afforded by this experiment. Graft elongation *per se* has not been satisfactorily proved, however, by marking techniques. The nature of the spanning fiber is as yet unknown.

Conversion of Adult Skeletal Muscle to Bone in Tissue Culture. Dr. C. Andrew L. Bassett [15] reported that strains of cells derived from human adult skeletal muscle and cancellous bone have been grown in continuous propagation for periods in excess of one year. Periodic assay of certain morphological and histochemical features of these cells has failed to reveal any characteristics that serve to differentiate one strain from the other. Large intracytoplasmic alkaline-phosphatase concentrations have been found in the cells of muscle and bone cultures. In addition, a profusion of para-aminosalicylic-acid positive granules has been found in the cytoplasm of these cells. The supernatant "used" medium from muscle and bone cultures has given evidence of high-polymer mucopolysaccharide production. By adjusting the tissue-culture environment, "de-differentiated" cells of muscle origin have been "induced" to form a matrix having the histological and tinctorial characteristics of osteoid-chondroid material. Some of the factors leading to this differentiation were analyzed.

The Effect of Arteriovenous Fistulae on the Blood Vascular Pattern of the Femora of Immature Dogs. A Micro-angiographic Study. Dr. Patrick J. Kelly [16], Dr. L. F. A. Peterson, and Dr. J. M. Janes, aware of the fact that an arteriovenous fistula increases bone length in the immature dog and human, and wishing to further elucidate the mechanism of bone growth, have analyzed the changes occurring in the vascular pattern of sixteen dogs with surgically created arteriovenous fistulae. The techniques were previously reported by Peterson, Kelly, and Janes in Proceedings of the Staff Meetings of the Mayo Clinic, **32**: 681-687, Nov. 27, 1957.

Approximately 1000 individual micro-angiograms have been reviewed in this study. In addition, gross arteriograms were made on each dog, and temperature studies of the femora were performed by utilizing thermistors.

The papers read at the Combined Program of The Orthopaedic Research Society and The American Academy of Orthopaedic Surgeons are summarized in the Proceedings of The American Academy of Orthopaedic Surgeons.

14. The Johns Hopkins Hospital, Baltimore 5, Maryland.
15. Columbia University, College of Physicians and Surgeons, New York, N. Y.
16. Mayo Clinic, Rochester, Minnesota.

AMERICAN SOCIETY FOR SURGERY OF THE HAND

The Fourteenth Annual Meeting of the American Society for Surgery of the Hand was held January 23 and 24, 1959, in Chicago, Illinois, under the Presidency of Dr. George V. Webster of Pasadena, California.

Friday, January 23

Heterogenous and Autogenous Tendon Transplants. Dr. J. Edward Flynn [1], Dr. John T. Wilson, Dr. Charles G. Child, III, and Dr. James H. Graham studied the healing process of heterogenous and autogenous tendon transplants in three series of experiments in dogs. In experiment one, twelve young bovine tendon transplants, preserved in homologous serum, were used; in experiment two, nine transplants of embryonic, frozen, bovine tendon, and in experiment three, twelve autogenous transplants were studied. In all three experiments, the reactions were similar. During the first two weeks, union between the stumps of the host tendon and the transplanted tendon was effected mainly by proliferation of peritendinous tissue. The proximal and distal tendon stumps of the dog presented great tenoblastic activity with many mitoses and an increase in blood vessels. It is of interest that complete ischaemic necrosis occurred in all transplants. Some investigators have reported tenoblastic activity by the autogenous transplant but none was seen in these experiments. Invasion of all transplants occurred from the stumps of the host tendon by tenoblasts. This tenoblastic invasion was first by finger-like projections. Eventually, there was complete replacement of the transplants by tenoblasts and, later, by adult tendon cells. Some variation in reactions was noted in the three experiments. The time of appearance of new collagen and stress lines in the tenoblasts as well as the time of complete replacement of the transplants by tenoblasts and adult tendon cells was earlier with autogenous than with the heterogenous transplants. A probable antigen-antibody reaction was seen seven and eight weeks after insertion of the young bovine tendon which had been preserved in homologous plasma. This reaction was characterized by plasma-cell clusters and rheumatoid-like nodules. It is probable that the antigen came from the plasma. Sheaths with synovial membrane formed around the young bovine tendon which had been preserved in homologous plasma.

In the discussion Dr. Michael L. Mason [2] said that there is still a great deal of experimental work to be done on this subject. He noted that the work of Dr. Flynn and his associates corroborates to a large extent his own experiments done with Dr. Shearon and Dr. Harvey Allen some years ago. He took issue with the author on the question of the viability of the grafts, pointing out that it is extremely difficult to determine the exact source of the proliferating cells. He felt that in many instances there was evidence of cellular proliferation in the ends of the grafts and that many of these were bundles of tendon cells. It was his opinion that although the graft may not remain viable throughout its whole extent there are sections which do remain viable. The smaller grafts of lesser diameter remain largely viable and persist as viable tissue.

Dr. E. E. Peacock, Jr. [3], said that Dr. Flynn's work represents a contribution to our basic knowledge in the general field of tissue transplantation. Tendons are relatively simple structures; they contain only three elements, collagen, ground substance, and fibrocytes. Thus, they offer an unusual opportunity to study relatively simple preparations of these three tissue elements following heterologous and homologous transplantations. The experiments reported here show the fate of the fibrocyte. The ground substance could be studied in a similar manner by utilizing differential histochemical staining techniques. The antigenicity and fate of collagen is more difficult to ascertain because with present methods it is extremely difficult to obtain pure collagen—even by acid extraction and subsequent reconstitution. C^{14}-glycine labeled tendons or tendon transfers performed on scorbutic animals might be useful in this regard. As the ultrastructure and clinical properties of the collagen molecule are revealed, we who, perhaps more than any other group of surgeons, are at the mercy of uncontrolled fibrous-tissue formation, have a grave responsibility to be continually searching for applications of new fundamental principles to the clinical problems of scar formation in the healing wounds of human hands.

Primary Repair of Flexor Tendons. Dr. Claude Verdan [4] stated that the course hitherto adopted of tendon-grafting instead of immediately repairing flexor-tendon lacerations in Bunnell's no-man's land is too rigorous. It is only justified for those having no experience in hand surgery or when general or local conditions do not allow immediate repair.

In clean, fresh wounds, the specialist who is capable of doing a tendon graft correctly is *a priori* qualified to do primary tendon sutures. The technique proposed by the author consists in excising the sublimis, suturing the profundus accurately with fine epitendinous stitches,

1. 412 Beacon Street, Boston 15, Massachusetts.
2. 154 East Erie Street, Chicago 11, Illinois.
3. University of North Carolina, Chapel Hill, North Carolina.
4. Lausanne, Switzerland.

resecting the sheath at the point of affrontment, and fixing the ends with two transverse stainless-steel pins, preventing tension on the delicate suture line which is comparable to that of a sutured nerve. Should adhesions hinder gliding, a secondary tenolysis procures functional results often better than those obtained by tendon grafts.

For multiple simultaneous flexor-tendon lacerations in several fingers, primary repair is even more justified than for one alone.

Dr. Michael L. Mason [5] said, in discussion, that the only area of the hand where there is major disagreement concerning primary tendon repair is the so-called no-man's land. Not so many years ago the grafting of tendons in this area was undertaken with little assurance of success. Today tendon grafts are used here without hesitation when the conditions are satisfactory and the surgeon well trained in the necessary technique, even though tendon grafts in the digits are by no means always completely successful. Dr. Mason outlined the basic surgical principles governing tendon repair, noting the author's use of transfixion pins to minimize surgical trauma to the tendon ends and citing similar techniques developed by other surgeons.

He made a plea that a completely pessimistic or defeatist attitude not be taken toward primary repair in this critical zone. He stressed that this is a most frequent site for tendon division and that when conditions are favorable it is most advantageous to the patient to do primary repair if this can be carried out with reasonable assurance of success. Only by constantly striving for better techniques, by following the example of the plastic surgeon, and by observing the principles of tendon repair, can this assurance of success be obtained.

Dr. Joseph H. Boyes [6] drew attention to the importance of excision of the sheath at the point of primary repair, noting that a flexor tendon does not necessarily have to have a tendon sheath in order to function, as is commonly believed. Many tendons in the body do not have sheaths. Excision of the sheath allows a blood supply to be provided to both a primary repair and a tendon graft. A tendon graft in the finger will not survive without a blood supply. If a tendon is put through the sheath it will die. Similarly, as Gonzalez showed, putting polyethylene around a tendon cuts off its blood supply. Dr. Boyes stated that blood supply for a repaired tendon comes from the contiguous soft tissues and expressed doubt as to value of the transfixion pins in obtaining relaxation of the tendon.

The Study of Flexor Tendons and Their Coverings in the Process of Repair. Dr. Martin Entin [6] reported an exhaustive study in dogs on the influence of the various coverings of the flexor tendons on the process of tendon repair after primary suture and tendon-grafting. An area in the dog's extremity was selected, which was felt to be comparable to Dr. Bunnell's no-man's land in the human hand. The tendon graft was found to heal best, with greatest tensile strength, if it was covered only with peritenon. Healing was slower and accompanied by more scar if paratenon or fascia was wrapped about the graft. The author concluded that it was wise not to place obstacles in the area where the blood supply is attempting to cross over from the intact tendon into the tendon graft. He felt that putting heavy silk or wire sutures at this site tended to constrict the graft and that a fine suture was preferable. He emphasized that one should be careful when removing the sublimis tendon from the finger, being certain to split it in order not to disturb the blood supply to the profundus tendon as the sublimis tendon is being removed.

In discussion, Dr. Robert E. Carroll [7] said that if the paratenon is preserved about a tendon graft, it will be a firm and early barrier of scar tissue, blocking the new blood supply. This will cause adherence and diminish excursion of the grafted tendon. Therefore, only a tendon which has been divested of this scar-forming tissue should be used for a graft. Also of importance is the bed in which tendon repair is to take place. Should a free graft be inserted, all of the previous sheath except for the annuli which are preserved for pulleys, should be removed. When primary tendon repair is to be carried out, here also the adjacent sheath should be sectioned and removed. Dr. Carroll commented on the need for a method to reconstruct the gliding mechanism of the flexor tendons and stated that Dr. Entin's work had made a valuable step in this direction.

Experimental and Clinical Studies on the Application of Monomolecular Cellulose Filter Tubes to Create Artificial Tendon Sheaths in the Hand. Dr. Franklin L. Ashley [8] reported encouraging results following the use of a nylon-mesh cellulose material (Millipore-Microweb) to create artificial tendon sheaths in laboratory animals and human beings. Postoperative function in patients and microscopic appearance of the sheaths in animals compared favorably with appropriate controls.

Dr. J. Edward Flynn [1] in discussion asked whether Dr. Ashley in his reconstruction had made any attempt to preserve the annular ligaments within the digits. He said he had repaired the paratenon, but he felt that when this was done a silk suture of the tendon was too bulky. He wondered whether the mesh cellulose material increased the capacity of the sheath.

5. 1401 South Hope Street, Los Angeles 15, California.
6. Medical Arts Building, Montreal, Quebec, Canada.
7. 180 Fort Washington Avenue, New York 32, N. Y.
8. 405 Hilgard Avenue, Los Angeles 24, California.

DR. GEORGE V. WEBSTER[9] pointed out that Dr. Ashley would be quick to admit that he has had a number of poor results and that this is not the final answer. However, it is a step in the right direction, using the experimental approach. Dr. Ashley's work is notable since it furthers the use in the hand of this material which has already been used effectively by the neurosurgeons who pioneered its use.

DR. ASHLEY answered Dr. Flynn's question by saying he had made every attempt to preserve the pulleys while removing the remainder of the synovial sheath. In work of this nature, it should be mentioned that no study is complete without accurate evaluation of the tensile strength of the injured and repaired tendons. This evaluation is under way, using two methods: the so-called mechanical tensiometer and the method of Dunphy and collagenase levels.

The Pathogenesis of Dupuytren's Contracture. Experimental and Further Clinical Investigations. DR. ROBERT D. LARSEN[10], DR. NAHOTO TAKAGISHI, and DR. JOSEPH L. POSCH[11] reported further on the work that was begun in 1956, in which they found hemosiderin pigment in the early Dupuytren nodule, and abrupt terminations of the collagen fibers which seemed to suggest minute traumatic ruptures. In forty-eight extremities of monkeys, minute tears of the plantar fascia were produced in a controlled manner. Microscopically the lesions which were found following such rupturing of the plantar fascia resembled those seen microscopically in Dupuytren's contracture in human beings. The same microscopic picture could be demonstrated in the anterior rectus sheath of the dog after rupture of the fascia in a similar manner. In none of the monkeys, however, did a true contracture of the toes develop during the period of study. The authors emphasized that it was not intended to imply that microrupture of the fascia was the only etiological factor in Dupuytren's contracture, but they suggested that microrupture of the palmar fascia might be one of the triggering mechanisms which starts the formation of the contracture in an individual whose fascia has some type of predisposition making it susceptible to the contracture. It was pointed out that Dupuytren's contracture occurs in Negroes and in the Japanese as well.

DR. JULIAN M. BRUNER[12] said, in discussion, that the histological observations of the immature and the mature types of tissue, the absence of elastic fibers, the presence of hemosiderin pigment suggesting *hemorrhage*, and the abrupt termination of fibers suggesting rupture, are all exceedingly provocative. It seems fairly well accepted that Dupuytren's contracture arises in predisposed individuals, many of whom give a family history of the same condition. If there is also a traumatic factor, the question arises as to what kind of trauma this may be. Evidently, Dr. Larsen, Dr. Takagishi, and Dr. Posch believe that this trauma is in the nature of tension, stretching, or rupture of the fascia, rather than the direct trauma to the palm which is sustained by manual laborers or baseball and handball players.

It is likely that if rupture of fibers is the causative factor in predisposed persons, the trauma must be minor in nature and repeated infinitely over a period of years. The distribution of Dupuytren's contracture in the human palm seems to support this concept. Longitudinal stress in the palmar fascia is produced by hyperextension of the fingers, and is greatest in the ulnar element of the hand where the range of hyperextension as well as flexion is greatest in the metacarpophalangeal joint of the little finger, slightly less in the ring finger, and progressively less in the long and index fingers.

Transverse stress in the palmar fascia is produced by intermetacarpal movement. This is greatest between the fixed and the movable pillars of the hand, that is, near the base of the ring finger. This coincides with the point at which the greatest hyperplasia of the palmar fascia is seen clinically.

Advancing age and sedentary occupation may also render the fascia more vulnerable to tension, which would explain why the palmar fascia of the white-collar worker may be more susceptible to the trauma of stretching than that of the manual laborer whose aponeurosis undoubtedly has greater tensile strength.

DR. S. BENJAMIN FOWLER[13] stated that he had never seen Dupuytren's contracture in a Negro, although he supposed it does occur. He had also never seen Dupuytren's contracture in a person in whom there was not something else wrong.

Selective Procedures in the Cerebral Palsied Hand. DR. ALFRED B. SWANSON[14] noted that in cerebral palsy the majority of deformities in the upper extremity are best treated by bracing, stretching, and muscle re-education. The major handicap is inability to open the hand for grasp. Flexor spasm usually predominates at the wrist and in the fingers. In selected cases the restoration of balance between the flexors and extensors of the wrist, fingers, and thumb can restore adequate grasp, release, and pinch without wrist arthrodesis. The extensor mechanism of the fingers is often out of equilibrium as manifested by the intrinsic-plus deformity.

9. 1145 East Green Street, Pasadena 1, California.
10. 1405 Kales Building, Detroit 26, Michigan.
11. 1405 Kales Building, Detroit 26, Michigan.
12. 1005 Bankers Trust Building, Des Moines 9, Iowa.
13. 1919 Hayes Street, Nashville 4, Tennessee.
14. Blodgett Medical Building, Grand Rapids 6, Michigan.

In cerebral palsy this deformity is usually secondary to chronic wrist flexion which increases tension on the middle band of the long extensor. The resultant relative shortening of the middle band causes hyperextension of the proximal interphalangeal joint and flexion of the distal interphalangeal due to joint relaxation of the lateral bands. Once established the deformity becomes self-perpetuating. Correcting the deformity will re-establish balance of the finger. The author proposed tenodesis of the sublimis tendon with the proximal interphalangeal joint held in flexion as a method of correcting the intrinsic-plus deformity and suggested also that bracing of the spastic hand should prevent hyperextension of the proximal interphalangeal joints.

DR. S. BENJAMIN FOWLER [15] emphasized that tendon transfers are extremely difficult to make to work in patients with cerebral palsy because it is difficult to train them to use a transplanted muscle in a different capacity. If the tendon transfer does not work, tenodesis can be done. In some patients with a wrist-flexion deformity secondary to spasticity, the extensor carpi ulnaris tendon may become displaced to the volar side of the wrist and actually block extension of the wrist by acting as a flexor instead of an extensor of the wrist. In a few patients the extensor tendon at the metacarpophalangeal joint tends to subluxate, in which case it fails to extend the metacarpophalangeal joint well. In other instances there may be a snapping of the extensor-tendon mechanism across the proximal interphalangeal joint or the metacarpophalangeal joint may tend to subluxate in a volar direction. One method of correcting the snapping of the extensor tendon across the proximal interphalangeal joint is tenodesis of the extensor tendon with the interphalangeal joint in complete extension. This removes the primary extensor force from the interphalangeal joint and at the same time tends to prevent volar subluxation of the metacarpophalangeal joint.

Objective Method of Evaluating Hand Sensation and Its Use in Reconstructive Surgery. DR. ERIK MOBERG [16] described a method for mapping the return of sensation in the hand after injury to peripheral nerves and repairs by nerve suture or nerve graft. A special type of sensitized paper, known as ninhydrin paper, which is similar to that used for fingerprinting, was employed. Since the sympathetic fibers, which course through the peripheral nerves, supply the sweat glands, sweating is present only in the area of normal sensation and no fingerprint is obtained if the area is completely denervated. Dr. Moberg pointed out that it is the quality of sensory return which is important in an extremity. He felt that seldom, if ever, following nerve laceration and nerve repair does one obtain completely normal return of sensation. He found that flaps and grafts, after a prolonged period of time, did show sweating but a two-point discriminatory type of sensation never developed. An interesting movie showing the type of function achieved in a hand after repair of a severed peripheral nerve was presented to illustrate the fact that following nerve suture and regeneration the patient has difficulty with fine functional movements of the fingers unless he utilizes visual perception to guide finger function. Dr. Moberg felt that this technique of checking sensory return in extremities should be utilized more widely for it offers a much more objective index of return of sensation to an area than any of the subjective tests in use.

DR. J. WILLIAM LITTLER [18], in discussion, said that the test is particularly significant because it gives an objective test for sensory loss. In reporting nerve loss to compensation boards or in private cases when reconstruction is planned, these maps are extremely important.

The Sublimi and Finger Balance. DR. WILLIAM L. WHITE [17] pointed out that the role of the sublimis in normal finger balance is principally that of providing strength and smooth and coordinated flexion of the digit. Its removal may cause little disturbance in a finger that is otherwise normal. In a limber finger, its removal may result in the development of recurvatum as well as weakness and incoordinate flexion. If the sublimis is removed from a finger, rerouted, and inserted on the lateral bands for correction of intrinsic palsy, recurvatum will almost invariably develop, particularly in hypermobile hands where an intrinsic-plus deformity will frequently result after several years due to the overpowering intrinsic force exerted by the transplant. The role of the sublimi in other states of finger imbalance was also considered.

Tendon Transfers Following Ulnar-Nerve Injury. DR. J. LEONARD GOLDNER [19] (no abstract submitted).

Reconstructive Arterial Surgery in Upper-Extremity Injuries. DR. ROBERT S. SHAW [18] made a plea for primary restoration of arterial continuity in cases of upper-extremity trauma involving injury to major arteries. He pointed out the high incidence of limb loss in such injuries, particularly when there is concomitant injury in the distal portion of a relatively ischaemic extremity, and noted that restoration of arterial continuity can be rewarding even in neglected

15. Göteborg, Sweden.
16. 14 East 90th Street, New York 28, N. Y.
17. University of Pittsburgh, Pittsburgh 13, Pennsylvania.
18. Duke University Hospital, Durham, North Carolina.
19. Massachusetts General Hospital, Boston 14, Massachusetts.

cases seen late. Excellent blood flow through the repaired vessel is essential to success. This requires scrupulous attention to the avoidance of stricture at the suture line and complete removal of distal thrombus in the artery. The thrombus may be removed by retrograde flushing from an unthrombosed point in the distal artery or by the use of special instruments. Re-exploration in the case of postoperative thrombosis was urged; this will commonly convert failure to success when the reason for thrombosis is recognized and corrected. The free use of venous autografts was recommended. Extremes of heat and cold should be avoided in the extremity with marginal circulation since both can cause serious tissue injury. The extremity should be warmed to a temperature of from 80 to 90 degrees Fahrenheit. Even severe degrees of ischaemic injury following long periods of circulatory arrest will heal and allow salvage of a useful extremity if circulation is restored.

In discussion Dr. Bradford Cannon [20] pointed out that no group of surgeons is more aware of the importance of blood supply for tissue nutrition than hand surgeons. He said he well remembered Dr. Bunnell's fascination at the improved suppleness of the skin and general condition of the badly injured hand when a flap was used to replace avascular scar tissue. He reviewed the development of Carrel's vascular anastomosis for experimental kidney transplants and Crile's anastomosis of artery to vein as a method of direct transfusion in the human being and pointed out that during World War I it had been observed that simultaneous ligation of the vein when the artery was severed had a beneficial effect. He noted that in World War I the extremity with impaired circulation was promptly amputated. Because of better débridement and because of safer prophylaxis against tetanus and gas infections it was possible to salvage many extremities with impaired circulation in World War II. He pointed out that it was not until the Korean War that the pioneer teachings of Carrel and Crile were applied to the treatment of lacerated vessels of the extremities resulting from warfare. The surgeon of today must be familiar with vascular anastomosis and must be ready to do the more time-consuming restoration of continuity rather than the simpler, but defeatist, ligation. He was impressed by Dr. Shaw's emphasis on the obvious importance of extracting or evacuating the distal thrombus.

The Versatile Cross-Finger Pedicle Flap. Dr. H. Dean Hoskins [21] said that significant loss of the soft-tissue covering of a hand digit as a result of trauma or surgical procedure is not uncommon. Under certain circumstances the use of a pedicle flap of skin and subcutaneous tissues will provide maximal functional and cosmetic repair. Palmar, thenar, chest, and abdominal donor sites have been used but all have distinct disadvantages. The cross-finger pedicle flap eliminates some of these disadvantages. Within the limits of the amount of cover available, it has proved highly satisfactory in covering defects of any area of the thumb or fingers. Dorsal skin from the proximal or middle segments of an adjacent finger is used as a donor site for the pedicle flap. Smaller flaps may be based in any direction while larger flaps are based either laterally or proximally. The donor site on the donor digit, including the bridge, is covered with a split-thickness skin graft to create a closed system.

Of the twenty-four cases reported, there were good to excellent results in nineteen; in the four with fair results there was non-disabling limitation of flexion or extension in one of the involved digits. The result in one was rated poor because of persistent tenderness.

The advantages claimed for the procedure included technical ease, excellent viability of the flaps, comfort of the position during attachment, minimal disability since all operative areas are on the same extremity, minimal hospitalization, lack of scarring on a work surface of a hand or finger, provision of excellent cover which does not require either secondary defatting or scar excision, and excellent cosmetic and functional results. The major disadvantage (as with all pedicle flaps) is the lack of acute sensation in the reconstructed areas although protective sensation does develop. It was reported that the procedure is being used with increasing frequency and regular success when pedicle-flap coverage of a finger defect is deemed desirable.

Dr. Raymond M. Curtis [22] said he believed that the cross-finger pedicle flap is not so widely used in reconstructive surgery as it should be. He confessed that when Tempest, Horn, and others began to write about this procedure he began to use the technique with a great deal of hesitancy because of the possible disability which might be created in the normal donor finger. It was only after seeing the final result in a group of patients that he felt justified in advocating this method of treatment for certain types of finger injuries.

With reference to technique, Dr. Curtis pointed out that Dr. Bunnell repeatedly emphasized that the pedicle flap should not be made exactly the same size as the defect. If the defect in the injured finger is one inch in width, then the pedicle flap should be one and a quarter inches wide. He also stressed the need for dividing a layer of oblique fascial fibers, which cause the skin of the finger to be adherent to the extensor-tendon mechanism and to the periosteum laterally in order to gain length in the pedicle flap. The skin graft on the donor finger should also line the raw surface of the pedicle flap. The flap may be separated in ten to fourteen days.

20. 275 Charles Street, Boston 14, Massachusetts.
21. 200 29th Street, Oakland 9, California.
22. 2919 St. Paul Street, Baltimore 18, Maryland.

Reconstruction of a Grasping Mechanism Following Extensive Loss of Digits. Dr. Elden C. Weckesser [23] reviewed twenty-four cases of partial destruction of the human hand and presented fourteen personally supervised cases from University Hospitals, Cleveland. The value of finger length in grasping irregular-shaped objects and of the width of the palm in grasping heavy tools firmly was emphasized. The author stressed the value of retaining every portion of the hand, illustrating this point by presenting a patient with effective grasp between a first metacarpal remnant and the forearm.

Primary treatment by an experienced surgeon interested in this problem was recommended. The great importance of re-establishing the alignment of bone structures and providing skin coverage in addition to débridement was emphasized. Late reconstructive procedures, such as deepening of interdigital clefts, improving skin coverage, tendon transfers, and reconstruction of parts by pedicle flap and bone graft, were found most useful. Normal skin coverage for the grasping mechanism was considered most desirable. However, when this was not possible, useful digits which were kept short were reconstructed by pedicle flap and bone graft. To illustrate this point a patient was presented, who, after ten years, had a useful grasp with digits covered with pedicle-flap skin. Other patients with shorter follow-up periods were also presented.

In discussion, Dr. Walter C. Graham [24] discussed delayed treatment to improve prehension in severely damaged hands. Unless something is done to restore grasp, these hands have little more function than a paper weight. By transplanting a portion of the second metacarpal to lengthen the first and by resecting the rest of the second metacarpal to deepen the cleft, a lobster-claw hand can be fashioned which increases the grasping area tremendously. In Dr. Graham's experience, a more permanent, deep cleft can be established if a local flap of normal living skin is used at the base of the cleft, as is done in syndactylism. The advantage of this procedure is that the local flap prevents the distal migration of the cleft and also maintains the width of the base of the cleft which is essential for the grasping of a larger object. An attempt should also be made to turn the skin with normal sensation into the cleft so that the areas of contact will have normal sensation.

Dr. Graham noted that in his experience the lengthening of appendages by tube pedicles, which were later filled with bone grafts in order to give stability, had given discouraging results and he now avoids using them if at all possible.

Rotation and angulation osteotomies are extremely helpful in restoring thumb grasp and contact of the thumb with the remaining small fingers. Shortening of the first metacarpal may be useful in order to bring the tip of the thumb in contact with the surviving portion of the hand. Rotation at the site of osteotomy for shortening may be carried out so the pulp of the thumb will touch the more useful part of the remaining hand. Although pollicization has received a great deal of attention, Dr. Graham expressed the opinion that a normally functioning finger should not be removed from its normal position in an attempt to form a thumb. The fingers can grasp against the base of the hand and give a quite satisfactory grasp. One needs only to observe a patient with congenital absence of the thumb, or one with traumatic amputation of the thumb of long standing, to appreciate the excellent usefulness of such a hand and the tremendous ability of the index finger to approach the position and function of opposition without benefit of surgery. Knowing this one should hesitate to attempt to give something more useful. On the other hand, when the thumb is gone, and a digit on the radial side of the hand has been so severely damaged that it will not function in a normal manner, transplantation of this damaged finger to act as a thumb may be desirable. Dr. Graham presented a case in which the second toe was transplanted to form a grasping thumb in a child in whom all the digits had been lost in a wringer injury. The second toe was transplanted to the remaining portion of the first metacarpal. Both the flexor and extensor tendons were attached to provide motor function. Over four to five years increase in the size of the carpal and metacarpal bones has been demonstrated in this case and also, peculiarly enough, growth in the phalanges of the transplanted digit whose epiphyses are still healthy and growing. The child has developed a very powerful grasp against the stump of the fifth metacarpal, and has complete restoration of sensation.

Reconstruction of a Digit Following Loss of All Fingers with Preservation of the Thumb. Dr. G. N. Lassar [25] presented a case illustrating such an injury. Wound closure was achieved by a combination of a flap advancement and skin-grafting of the defect. Grasping mechanism was restored by mobilization of the thumb and reconstruction of a digit utilizing a transposed metacarpal and local skin flap. (This paper, together with the discussion by Dr. Phalen, was published in *The Journal of Bone and Joint Surgery*, **41-A:** 519-523, Apr. 1959.)

Symposium: Acute Trauma to the Hand and Its Complications. *Moderator:* Dr. William H. Frackelton [26]; Panel: Dr. Joseph H. Boyes [5], Dr. J. Edward Flynn [1], Dr. Erik Moberg [18],

23. 10463 Carnegie Avenue, Cleveland 6, Ohio.
24. 1421 State Street, Santa Barbara, California.
25. 1307 Washington Avenue, St. Louis 3, Missouri.
26. 324 East Wisconsin Avenue, Milwaukee, Wisconsin.

Dr. Daniel C. Riordan [27], Dr. Claude Verdan [4], and Mr. Alan Wakefield, F.R.C.S.[28] The participants were asked specific questions from the audience, as well as questions by Dr. Frackelton, on such subjects as primary as against secondary coverage of burns to the hand, primary as against secondary tendon-grafting, the use of antibiotics in hand injuries, and the etiology of sympathetic dystrophy.

27. 1538 Louisiana Avenue, New Orleans 15, Louisiana.
28. Melbourne, Australia.

DISCUSSION

Rheumatoid Synovial Cyst of the Hip

(Continued from page 780)

distally anterior to the gastrocnemius and tendo achillis and posterior to the soleus, nearly as far as the calcaneus. The character of the fluid contained in the cyst was similar to that described by Coventry and his co-authors and the microscopic study of the cyst wall revealed findings similar to theirs.

I have never seen cysts as large as these, and the fact that all of them developed in patients with rheumatoid arthritis who had been given steroid therapy seemed to be more than coincidental. This opinion was shared with me by Dr. Freyberg, Director of the Service of Rheumatic Diseases at the Hospital for Special Surgery.

In the cases reported by Coventry and his associates, it is interesting to note that when the patient in Case 3 was first seen he had been on cortisone therapy for four years and he exhibited marked evidence of hypercortisonism. It is also interesting to note that Case 1, a man fifty-six years old, showed in addition to the cystic mass of the left groin, bilateral popliteal cysts. This patient had previously been given ACTH therapy.

Cortisone exerts direct effect upon connective tissue. Among these effects is thinning and weakening of collagen fibers. It seems to me that if fluid accumulates under pressure in the joints of patients who are suffering from resistant or progressive rheumatoid arthritis, in whom it has been necessary to employ steroid therapy, that the fluid will naturally escape into adjacent bursal cavities, particularly into those that often communicate with the joint. If the structural strength of capsular ligaments and the bursal walls has been weakened by the effects of cortisone therapy, then the structures will offer little resistance and the sacs will distend along the anatomical planes of least resistance and will form effective traps for large accumulations of fluid.

I think the authors have done very well to put on record these interesting cases of synovial cysts of the hip joint. It will help us to recognize them, if and when we encounter them. If our theory is right, if they are at least, in part, due to the effect of cortisone therapy, and given the fact that there appears to be an expanding use of steroids in the treatment of patients with rheumatoid arthritis, then we are likely to be confronted by an increasing number of these cysts and there is also likelihood that some will develop in new and unlikely areas.

Dr. Coventry (closing): I think that these cysts should be removed if there is peripheral oedema. Whether they should be removed as a preventive measure to peripheral oedema is a rather moot point. I think it depends on the individual case; I would not urge it.

I enjoyed Dr. Wilson's remarks, particularly about the cortisone. I share his feelings about the patient in Case 3, who had the worst involvement and who was in a state of hypercortisonism.

However, the duration of ACTH therapy in the first patient was much too brief to attribute the presence of the cyst to this factor. The effects of steroids to which Dr. Wilson refers generally are related to the use of doses capable of producing hypercortisonism. Furthermore, cysts such as these were described long before cortisone was used. Our contribution is to place these cysts where we think they belong, as being caused by rheumatoid arthritis—having proved it, to a certain extent, by microscopic analysis.

Many rheumatic patients need to have the steroid dosage gradually reduced.

1958 Revision of Diagnostic Criteria for Rheumatoid Arthritis

Reprinted from the *Bulletin on Rheumatic Diseases*, Vol. 9, No. 4, December 1958, which is published by the Arthritis and Rheumatism Foundation, 10 Columbus Circle, New York 19, N. Y., Joseph J. Bunim, M.D., *Editor*.

CLASSIC RHEUMATOID ARTHRITIS

The diagnosis of classical rheumatoid arthritis requires seven of the following criteria. In Criteria Nos. 1 through 5, the joint signs or symptoms must be continuous for at least six weeks. (Any one of the features listed under "Exclusions" will exclude a patient from this category.)

1. Morning stiffness.
2. Pain on motion or tenderness in at least one joint (observed by a physician).
3. Swelling (soft-tissue thickening or fluid, not bony overgrowth alone) in at least one joint (observed by a physician).
4. Swelling (observed by a physician) of at least one other joint (any interval free of joint symptoms between the two joint involvements may not be more than three months).
5. Symmetrical joint swelling (observed by a physician) with simultaneous involvement of the same joint on both sides of the body (bilateral involvement of midphalangeal, metacarpophalangeal, or metatarsophalangeal joints is acceptable without absolute symmetry). Terminal phalangeal joint involvement will not satisfy this criterion.
6. Subcutaneous nodules (observed by a physician) over bony prominences, on extensor surfaces or in juxta-articular regions.
7. X-ray changes typical of rheumatoid arthritis (which must include at least bony decalcification localized to or greatest around the involved joints and not just degenerative changes). Degenerative changes do not exclude patients from any group classified as rheumatoid arthritis.
8. Positive agglutination test—demonstration of the "rheumatoid factor" by any method which, in two laboratories, has been positive in not over 5 per cent of normal controls—or positive streptococcal agglutination test.
9. Poor mucin precipitate from synovial fluid (with shreds and cloudy solution).
10. Characteristic histological changes in synovial membrane with three or more of the following: marked villous hypertrophy; proliferation of superficial synovial cells often with palisading; marked infiltration of chronic inflammatory cells (lymphocytes or plasma cells predominating) with tendency to form "lymphoid nodules"; deposition of compact fibrin, either on surface or interstitially; foci of cell necrosis.
11. Characteristic histological changes in nodules showing granulomatous foci with central zones of cell necrosis, surrounded by proliferated fixed cells, and peripheral fibrosis and chronic inflammatory cell infiltration, predominantly perivascular.

DEFINITE RHEUMATOID ARTHRITIS

The diagnosis of definite rheumatoid arthritis requires five of the preceding criteria. In Criteria Nos. 1 through 5 the joint signs or symptoms must be continuous for at least six weeks. (Any one of the features listed under "Exclusions" will exclude a patient from this category.)

PROBABLE RHEUMATOID ARTHRITIS

The diagnosis of probable rheumatoid arthritis requires three of the preceding criteria. In at least one of Criteria Nos. 1 through 5 the joint signs or symptoms must be continuous for at least six weeks. (Any one of the features listed under "Exclusions" will exclude a patient from this category.)

POSSIBLE RHEUMATOID ARTHRITIS

The diagnosis of possible rheumatoid arthritis requires two of the following criteria and total duration of joint symptoms must be at least three weeks. (Any one of the features listed under "Exclusions" will exclude a patient from this category.)

1. Morning stiffness.
2. Tenderness or pain on motion (observed by a physician) with history of recurrence or persistence for three weeks.
3. History or observation of joint swelling.

4. Subcutaneous nodules (observed by a physician).
5. Elevated sedimentation rate or C-reactive protein.
6. Iritis.

EXCLUSIONS

1. The typical rash of *disseminated lupus erythematosus* (with butterfly distribution, follicle plugging, and areas of atrophy).
2. High concentration of *lupus erythematosus* cells (four or more in two smears prepared from heparinized blood incubated not over two hours).
3. Histological evidence of *periarteritis nodosa* with segmental necrosis of arteries associated with nodular leukocytic infiltration extending perivascularly and tending to include many eosinophils.
4. Weakness of neck, trunk, and pharyngeal muscles or persistent muscle swelling or *dermatomyositis*.
5. Definite *scleroderma* (not limited to the fingers).
6. A clinical picture characteristic of *rheumatic fever* with migratory joint involvement and evidence of endocarditis, especially if accompanied by subcutaneous nodules or erythema marginatum or chorea. (An elevated antistreptolysin titer will not rule out the diagnosis of rheumatoid arthritis.)
7. A clinical picture characteristic of *gouty arthritis* with acute attacks of swelling, redness, and pain in one or more joints, especially if relieved by colchicine.
8. Tophi.
9. A clinical picture characteristic of acute *infectious arthritis* of bacterial or viral origin with: an acute focus of infection or in close association with a disease of known infectious origin; chills; fever; and an acute joint involvement, usually migratory initially (especially if there are organisms in the joint fluid or response to antibiotic therapy).
10. *Tubercle bacilli* in the joints or histological evidence of joint tuberculosis.
11. A clinical picture characteristic of *Reiter's syndrome* with urethritis and conjunctivitis associated with acute joint involvement, usually migratory initially.
12. A clinical picture characteristic of the *shoulder-hand syndrome* with unilateral involvement of shoulder and hand, with diffuse swelling of the hand followed by atrophy and contractures.
13. A clinical picture characteristic of *hypertrophic pulmonary osteoarthropathy* with clubbing of fingers or hypertrophic periostitis or both along the shafts of the long bones especially if an intrapulmonary lesion is present.
14. A clinical picture characteristic of *neuroarthropathy* with condensation and destruction of bones of involved joints and with associated neurological findings.
15. *Homogentisic acid* in the urine detectable grossly with alkalinization.
16. Histological evidence of *sarcoid* or positive Kveim test.
17. *Multiple myeloma* as evidenced by marked increase in plasma cells in the bone marrow, or Bence-Jones protein in the urine.
18. Characteristic skin lesions of *erythema nodosum*.
19. *Leukaemia* or *lymphoma* with characteristic cells in peripheral blood, bone marrow, or tissues.
20. *Agammaglobulinaemia*.

It is hoped that these revised criteria will aid in obtaining even more uniformity in the classification of patients with rheumatoid arthritis. Comments and suggestions for modifications or clarification will be welcomed. The criteria should be reviewed in two or three years and revised as necessary.

Marian W. Ropes, M. D. (Chairman)
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Ralph Jacox, M. D.
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Book Reviews

VITALLIUM MOULD ARTHROPLASTY FOR OSTEOARTHRITIS OF THE HIP JOINT. A Study of the Ability of the Method to Create a New Joint in an Anatomical-Physiological and in a Clinical Sense. Arnt Jakobsen. Oslo, Oslo University Press; New York, The Macmillan Company, 1957. $9.00.

This study is unusually well presented. The procedures and investigations were carried out in Surgical Department III, Oslo City Hospitals, and in the private practice of Professor Carl Semb. The work is properly dedicated to the memory of M. N. Smith-Petersen, M.D. In 1946, Dr. Smith-Petersen and Dr. Carroll Larson visited Norway and devoted several weeks to teaching a number of Norwegian surgeons Vitallium-mold arthroplasty of the hip. Twenty-three arthroplasties were performed by Dr. Smith-Petersen and Dr. Larson with the assistance of their Norwegian friends. The results of these arthroplasties stimulated the continuation of the use of the method. The study covers approximately 300 cases with observation periods of from three to seven years. All patients were treated by the same method.

The development of the surgical treatment of osteo-arthritis of the hip is briefly covered in a historical review. The early surgical procedure of excision or reduction of the size of the femoral head (modeling resection) and cheilotomy have limited use. Palliative measures, such as operating on the peripheral nerves or other parts of the nervous system, have been abandoned. These included obturator-nerve resection and resection of the nerve to the quadratus femoris, cordotomy, and fourth and fifth lumbar-nerve root resections. All gave discouraging results.

Temporary relief by palliative bone operations, such as drilling of the head and neck of the femur, osteotomy for changing the weight-bearing lines, and acetabuloplasty, have given way to more radical surgical procedures.

Soft-tissue operations such as capsulectomies and release of soft-tissue contractures have not been satisfactory. The more radical procedures of arthrodesis, arthroplasty, and insertion of a prosthetic femoral head of the stem and intramedullary type are also discussed.

A chapter on the symptoms of the osteo-arthritic hip is well presented and should be reviewed by all orthopaedic surgeons. It is not a complete review of the pain and I would disagree with some of the explanations, but it is worthy of study. The author conducted a study of pain by means of intra-articular hip-joint injections of 1 per cent zylocaine with adrenalin. No joint component was singled out as the source of pain. It seems reasonable to assume that there are four sources of pain: the synovial membrane, the fibrous capsule, the cancellous bone of joint ends, and the articular musculature.

He intimated that the pain on motion without weight-bearing is from the capsule, contracted muscle, and synovial membrane. For pain on weight-bearing, he presumed that the cancellous bone of the joint ends is primarily responsible; and for unstable joints, the fibrous capsule and contracted muscle. For pain at night, the cancellous bone ends were believed of greatest importance. Somatic pathways are credited with pain perception from the fibrous capsule and muscle. Autonomical pathways are thought to conduct pain arising from the synovial membrane and bone tissue. The nerves of the blood vessels are believed to be an essential part in the transmission and perception of pain.

The author's material is beautifully tabulated. It includes a thorough study of 250 patients with 301 hip operations. The indications for operation are pain, reduced mobility, and instability, either singly or combined. Pain was the principal indication.

Details of the surgical technique, with illustrations, are nicely presented. Modifications to fit individual cases are discussed and illustrated. The postoperative program is presented and a real understanding of the great demands of training atrophied muscle is evident. In the majority of cases a fairly systematic manipulation under anaesthesia is carried out at four to five weeks. The reviews question the value of the procedure except in rare instances.

Special complications were considered: dislocations in twenty-eight cases and peripheral nerve paralysis in six cases. The femoral nerve was involved in five of these; the paralyis was, however, of a transient nature. In only one patient was paralysis permanent.

Detailed studies were made in assessing the new joint in a clinical sense. Many methods of evaluation are described: the author's method is based on pain, mobility, and stability. The results were tabulated as: excellent, good, fair, and poor. The clinical estimate was made by the patient and the author. The imperfect results and the causes of such functional deficiencies are discussed in detail. Infection, dislocation, atrophy of the head and neck of the femur, new-bone formation, muscle weakness, and joint contracture are all assumed to be sources of a result less than that anticipated. However, technical error and insufficient postoperative treatment are at times a part of the cause. Continual examinations by the author have led him to conclude that clinical results usually become stationary. (It has been my experience that the majority of patients have improved as long as they have been under observation—now twenty-one years for some.)

There are twenty-seven plates illustrating all aspects of the study, including preoper-

ative and postoperative roentgenograms, gross-specimen photographs of a post-mortem hip, cross sections of a post-mortem hip, roentgenograms, and microphotographs. Numerous photographs of patients, demonstrating motion and stability, along with the preoperative and postoperative roentgenograms, add to this excellent presentation.

Otto E. Aufranc, M.D.

BONE TUMORS. Ed. 2. Louis Lichtenstein, M.D. St. Louis, The C. V. Mosby Company, 1959. $12.00.

The Second Edition of Lichtenstein's popular *Bone Tumors* comes to us seven years after the first. It hardly seems that enough new data could accumulate during that short interval to warrant a radical revision. Undoubtedly, it is prompted by what new data there are, by the changes the author has made in his own views, and by his desire to correct the deficiencies inevitable in a first edition. The new book has not discarded any significant material from the old, yet it is not much longer. It now has a foreword for pathologists and some remarks on the clinical management of bone lesions which may be tumors, as well as two short new chapters on periosteal and synovial tumors. Finally it has a ten-page elaboration of the appendix on non-neoplastic lesions which may be mistaken for tumors. This Second Edition has over 400 illustrations, perhaps 100 more than the previous edition. A few figures have been substituted, as improvements on the old; however, the newer figures illustrating osteoid osteoma are not so typical as the older. Aside from the references pertaining to the new chapters, about 100 new references are given from more recent literature.

Few new concepts have been introduced. In his classification, Lichtenstein has eliminated his previous group of atypical benign chondroid tumors (other than enchondroma, chondroblastoma, and chondromyxoid fibroma) and classifies them as chondromyxoid fibroma, thus enlarging his criteria for that entity. Similarly, the miscellaneous benign osteoid-forming tumors, other than osteoma and osteoid osteoma, are grouped under osteoblastoma.

The great majority of the chapters on individual tumors are duplications of those in the previous edition with, here and there, a sentence or reference added. Since some of the chapters were taken, in large part, from the now classic series of articles by Lichtenstein and Jaffe, one is somewhat at a loss to understand the basis for several changes in Lichtenstein's opinion on important matters. For example, in the First Edition, he states that the "best course to follow" for Ewing's tumor would be preliminary intensive radiation after biopsy followed by surgical extirpation. Now he says he is "more inclined to recommend irradiation rather than radical surgery". This change of heart, based on an added experience of ten cases according to his own statement, does not encourage the belief that such judgments are made on the facts alone. This is one instance where Lichtenstein indicates the magnitude of his additional experience in the interval between the two editions. He does so also for chondromyxoid fibromata and benign osteoblastomata, but in most other chapters the number of personal cases cited remains the same as that in the First Edition.

The chapter "Benign Osteoblastoma" has received extensive revision and is a welcome clarification of the previously muddled entity termed *osteogenic fibroma*. Added experience with this tumor has made it more worthy of separate recognition, although it is still not universally regarded as a distinct entity. The chapter on multiple myeloma has also been extensively enlarged to present the newer knowledge of the character of the abnormal protein.

Here and there short additions have been made to different chapters, to correct previous omissions—none of them serious. Other new comments, which have been inserted, are of interest: for example, the recognition of some osteoid osteomata, five to six centimeters in diameter; the willingness to accept a diagnosis of characteristic non-osteogenic fibroma on roentgenographic evidence, without biopsy; the steadfast confidence in the grading of giant-cell tumors contrary to the waning enthusiasm of others; the recommendation of pulmonary irradiation as a supplement to local treatment of osteogenic sarcoma and the opposition to considering parosteal osteoma (juxtacortical osteogenic sarcoma) as a separate entity.

Undoubtedly the book will continue to be one of the most popular if not the most popular text on this subject. The writing, not without flaws in style, lends itself to easy reading and reference, although the details are definitely less inclusive than in Jaffe's recent text. Lichtenstein has the courage to give his opinions forthrightly, and even in controversial areas they are never without a good basis of fact or rationale. If for no other reason, this text is well worth study by orthopaedists, roentgenologists, and pathologists. If the previous edition has already been studied, however, there does not seem to be a great deal to be gained by getting the new one.

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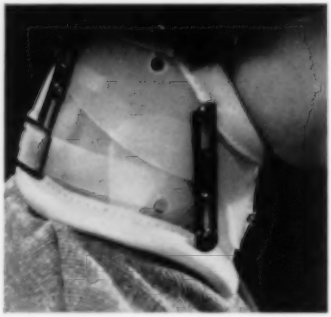

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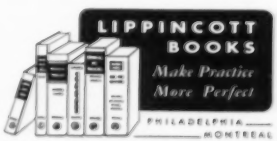

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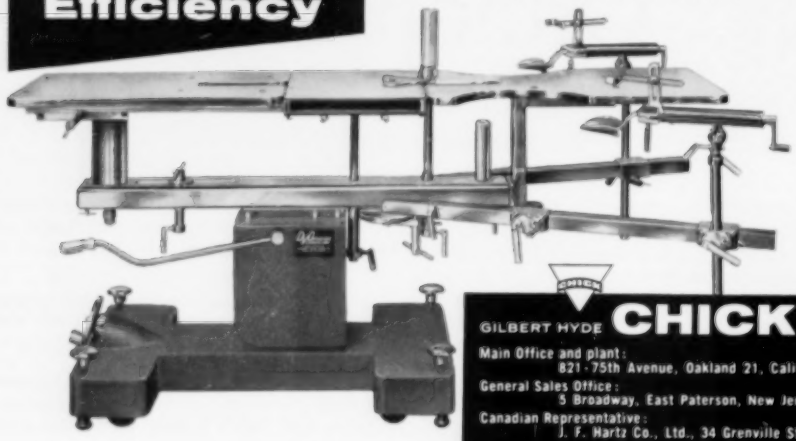

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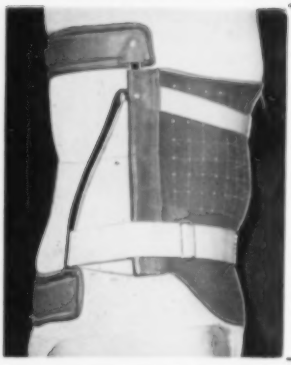

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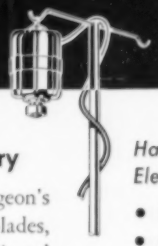

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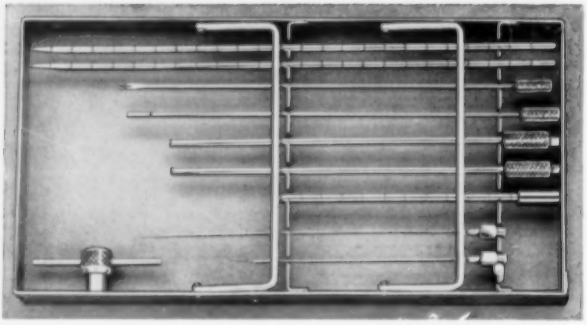

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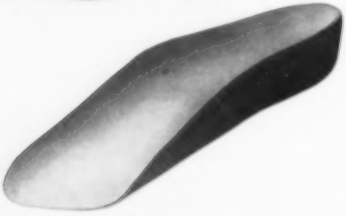

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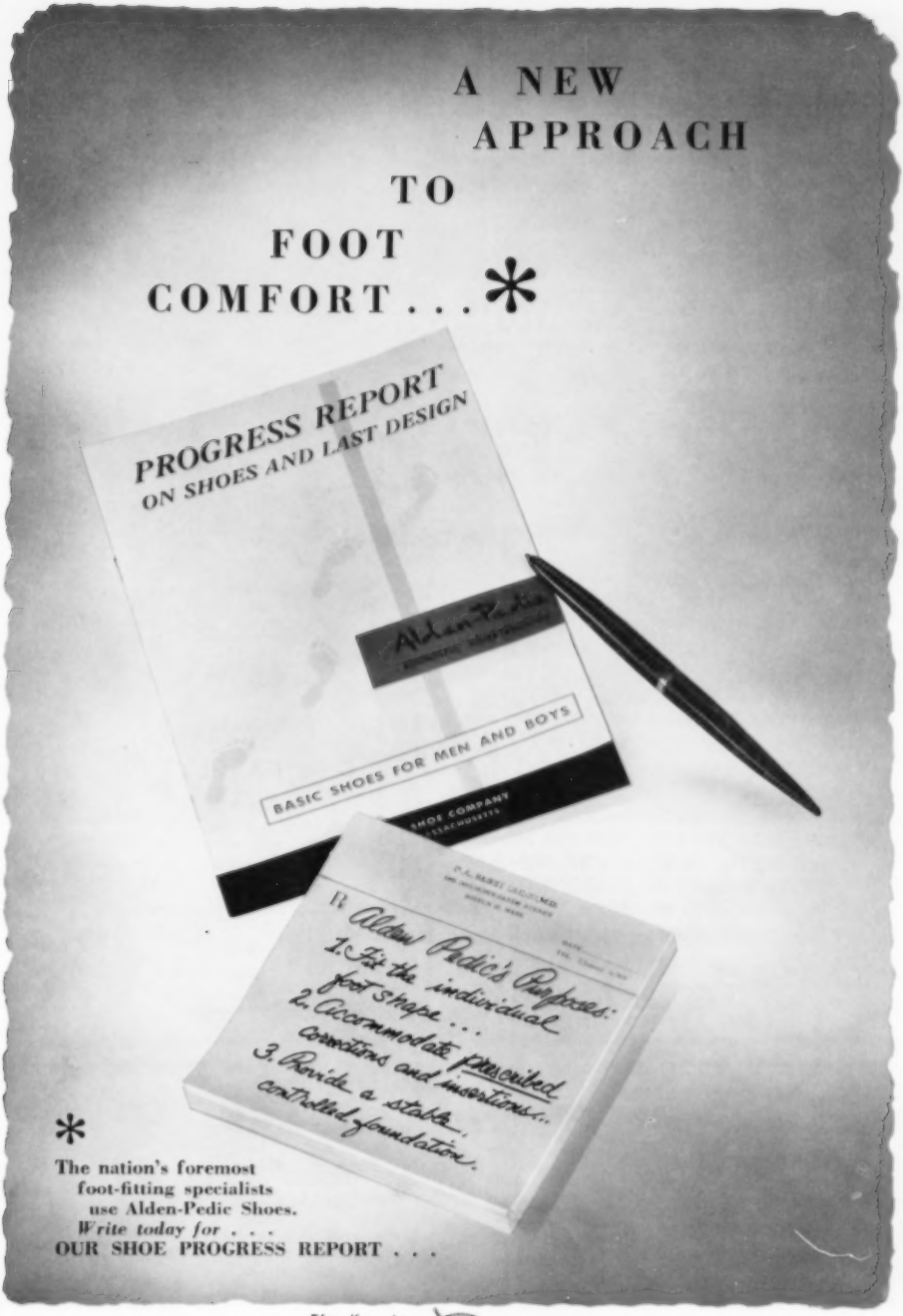
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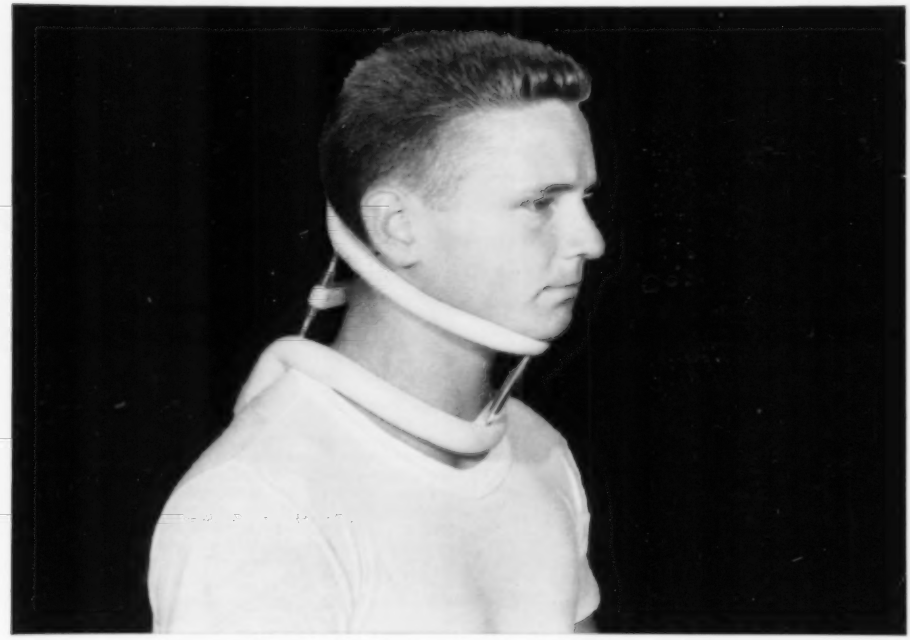

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List of Advertisers

JUNE 1959

	PAGE
Aireloom Bedding Company	63
C. H. Alden Shoe Company	57
American Sterilizer Company	13
Austenal, Inc.	5, 6, 7, 8
Ayerst Laboratories	26, 38, 39
Becton, Dickinson and Company	24
The Berivon Company	42, 43
Bowen & Company, Inc.	46
S. H. Camp and Company	59
G. W. Chesbrough Co.	9
Chesebrough-Pond's, Inc., Professional Products Division	4
Gilbert Hyde Chick Company	54
DePuy Manufacturing Company, Inc.	12
Eastman Kodak Company	23
Elgin Exercise Appliance Co.	61
Florida Manufacturing Corporation	52
Freeman Manufacturing Company	25
General Electric Co. X-Ray Dept.	16
J. E. Hanger, Inc.	22
Herbst Shoe Manufacturing Company	33
Hill Laboratories Company	56
House of Bidwell, Inc.	60
Johnson & Johnson	47, 48, 49
Kastoff Company	58
Kleistone Rubber Company	56
La Berne Manufacturing Company	34
Lederle Laboratories, Division of American Cyanamid Company	20, 21
J. B. Lippincott Company	53
McNeil Laboratories, Inc.	17
M. J. Markell Shoe Company, Inc.	58
Medical Research Specialties	44
Merck Sharp & Dohme, Division of Merck & Co., Inc.	50
Miller Brace Co.	54
Minnesota Orthopedic Services	58
The C. V. Mosby Company	51
V. Mueller & Co.	56
Orthopedic Equipment Co.	36
Orthopedic Frame Company	40, 55
Orthopedic Pocket Knife	63
J. A. Preston Corp.	52

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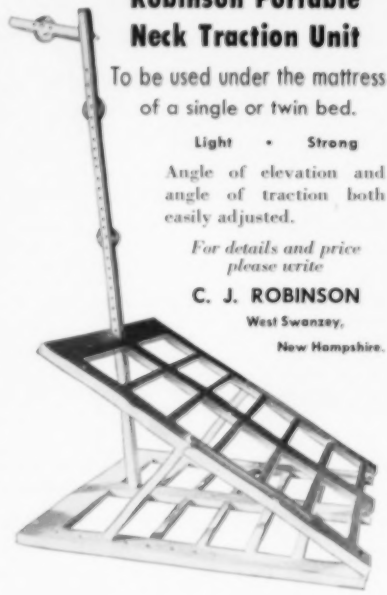

	PAGE
Richards Manufacturing Company	10, 11
C. J. Robinson	60
Chas. A. Schmidt Surgical Instrument Company	30
Sealy Mattress Company	61
Smith Kline & French Laboratories	41
Spencer, Incorporated	27
E. R. Squibb & Sons	28
Truform Anatomical Supports	29
The United Limb and Brace Co., Inc.	54
Wallace Laboratories	31, 45
H. Weniger	63
Winthrop Laboratories	37
Wright Manufacturing Company	32
Wyeth Laboratories	18, 19, 35
Zimmer Manufacturing Company	14, 15

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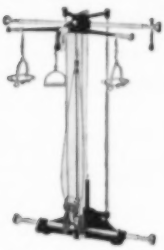

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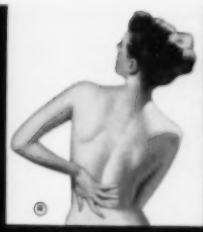

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